

The overview of the spin physics at RHIC-PHENIX experiment

Yoshinori Fukao
Kyoto Univ./RIKEN
for the PHENIX collaboration



13 Countries; 62 Institutions; 550 Participants*

- University of São Paulo, São Paulo, Brazil
- Academia Sinica, Taipei 11529, China
- China Institute of Atomic Energy (CIAE), Beijing, P. R. China
- Peking University, Beijing, P. R. China
- Charles University, Faculty of Mathematics and Physics, Ke Karlovu 3, 12116 Prague, Czech Republic
- Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering, Brehova 7, 11519 Prague, Czech Republic
- Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, 182 21 Prague, Czech Republic
- Laboratoire de Physique Corpusculaire (LPC), Université de Clermont-Ferrand, 63 170 Aubière, Clermont-Ferrand, France
- Dapnia, CEA Saclay, Bat. 703, F-91191 Gif-sur-Yvette, France
- IPN-Orsay, Université Paris Sud, CNRS-IN2P3, BP1, F-91406 Orsay, France
- Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS-IN2P3, Route de Saclay, F-91128 Palaiseau, France
- SUBATECH, École des Mines at Nantes, F-44307 Nantes France
- University of Muenster, Muenster, Germany
- KFKI Research Institute for Particle and Nuclear Physics at the Hungarian Academy of Sciences (MTA KFKI RMKI), Budapest, Hungary
- Debrecen University, Debrecen, Hungary
- Eötvös Loránd University (ELTE), Budapest, Hungary
- Banaras Hindu University, Banaras, India
- Bhabha Atomic Research Centre (BARC), Bombay, India
- Weizmann Institute, Rehovot, 76100, Israel
- Center for Nuclear Study (CNS-Tokyo), University of Tokyo, Tanashi, Tokyo 188, Japan
- Hiroshima University, Higashi-Hiroshima 739, Japan
- KEK - High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
- Kyoto University, Kyoto, Japan
- Nagasaki Institute of Applied Science, Nagasaki-shi, Nagasaki, Japan
- RIKEN, The Institute of Physical and Chemical Research, Wako, Saitama 351-0198, Japan
- RIKEN - BNL Research Center, Japan, located at BNL
- Physics Department, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima, Tokyo 171-8501, Japan
- Tokyo Institute of Technology, Oh-okayama, Meguro, Tokyo 152-8551, Japan
- University of Tsukuba, 1-1-1 Tennodai, Tsukuba-shi Ibaraki-ken 305-8577, Japan
- Waseda University, Tokyo, Japan
- Cyclotron Application Laboratory, KAERI, Seoul, South Korea
- Kangnung National University, Kangnung 210-702, South Korea
- Korea University, Seoul, 136-701, Korea
- Myong Ji University, Yongin City 449-728, Korea
- System Electronics Laboratory, Seoul National University, Seoul, South Korea
- Yonsei University, Seoul 120-749, Korea
- IHEP (Protvino), State Research Center of Russian Federation "Institute for High Energy Physics", Protvino 142281, Russia
- Joint Institute for Nuclear Research (JINR-Dubna), Dubna, Russia
- Kurchatov Institute, Moscow, Russia
- PNPI, Petersburg Nuclear Physics Institute, Gatchina, Leningrad region, 188300, Russia
- Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Vorob'evy Gory, Moscow 119992, Russia
- Saint-Petersburg State Polytechnical University, Politechnicheskayastr, 29, St. Petersburg, 195251, Russia

- Lund University, Lund, Sweden
- Abilene Christian University, Abilene, Texas, USA
- Brookhaven National Laboratory (BNL), Upton, NY 11973, USA
- University of California - Riverside (UCR), Riverside, CA 92521, USA
- University of Colorado, Boulder, CO, USA
- Columbia University, Nevis Laboratories, Irvington, NY 10533, USA
- Florida Institute of Technology, Melbourne, FL 32901, USA
- Florida State University (FSU), Tallahassee, FL 32306, USA
- Georgia State University (GSU), Atlanta, GA, 30303, USA
- University of Illinois Urbana-Champaign, Urbana-Champaign, IL, USA
- Iowa State University (ISU) and Ames Laboratory, Ames, IA 50011, USA
- Los Alamos National Laboratory (LANL), Los Alamos, NM 87545, USA
- Lawrence Livermore National Laboratory (LLNL), Livermore, CA 94550, USA
- University of New Mexico, Albuquerque, New Mexico, USA
- New Mexico State University, Las Cruces, New Mexico, USA
- Department of Chemistry, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA
- Department of Physics and Astronomy, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA
- Oak Ridge National Laboratory (ORNL), Oak Ridge, TN 37831, USA
- University of Tennessee (UT), Knoxville, TN 37996, USA
- Vanderbilt University, Nashville, TN 37235, USA

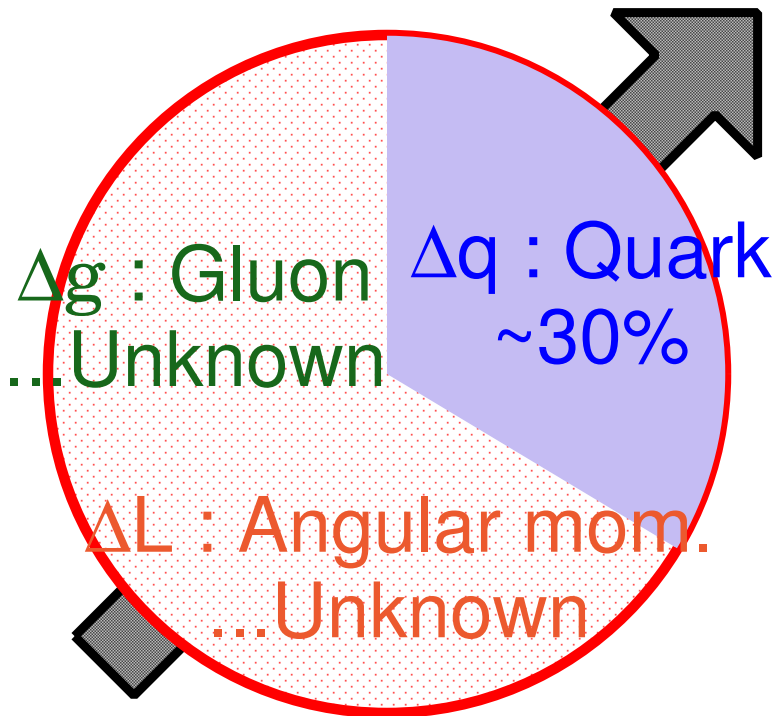
***as of March 2005**

Contents

- > Physics motivation
 - Gluon polarization in proton
 - Single transverse-spin asymmetry
 - W physics for polarized anti-quark distribution.
- > RHIC-PHENIX experiment
- > Local Polarimeter
- > Relative Luminosity
- > Physics Results
 - Neutral pion
 - Direct photon
 - "Jet"
 - Charged hadrons
 - Other topics
- > PHENIX in the future
- > Summary

Spin Physics at RHIC-PHENIX

How much does gluon spin align to proton spin?



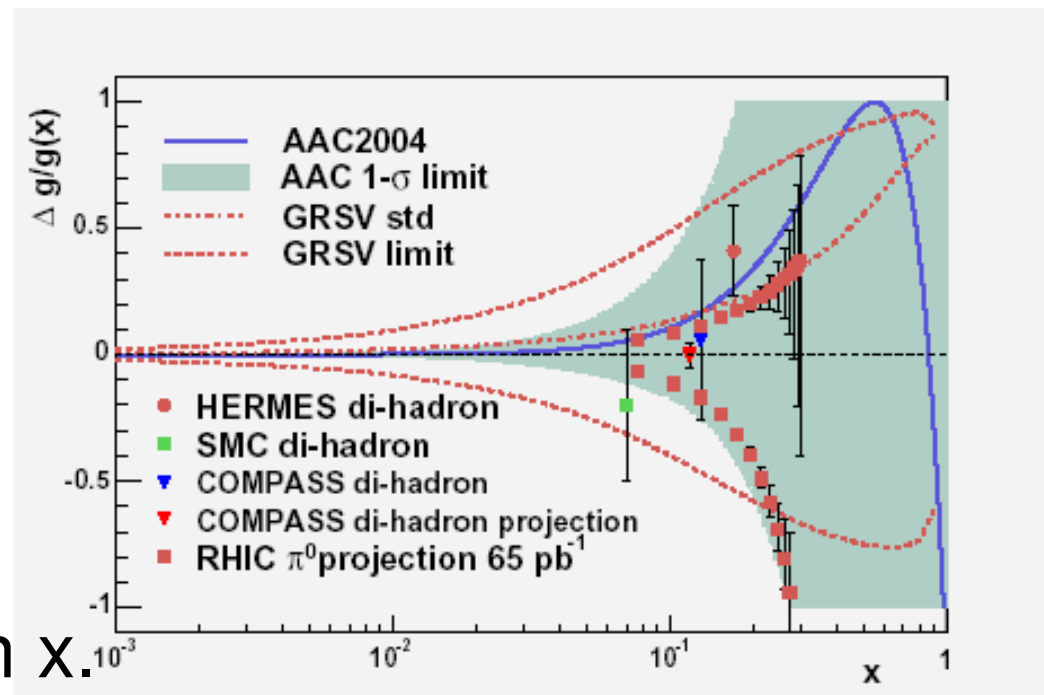
Proton structure, especially spin structure, is still unknown.



Shine a light on the gluon polarization Δg

$$\Delta g(x) = g_+^+(x) - g_+^-(x)$$

$g_+^{+(-)}(x)$: Probability to detect spin+ (spin-) gluon in spin+ proton as a function of Bjorken x .



Spin Physics at RHIC-PHENIX

How to measure Δg

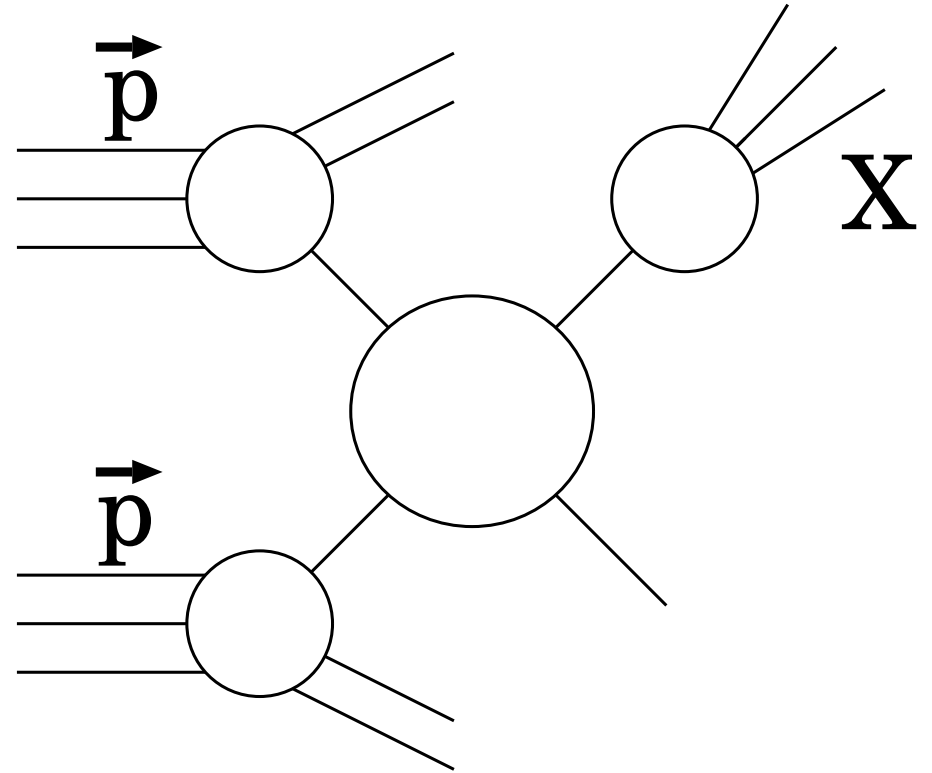
Measure A_{LL} in
 $\vec{p} \vec{p} \rightarrow X$ production.

X : Pions

Direct photon

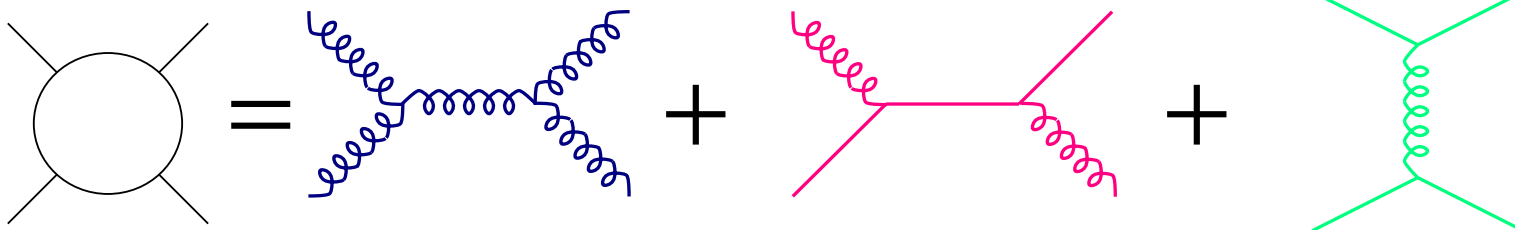
J/ψ

Any hadrons



$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$

$$\sim [\omega_{gg}] \left(\frac{\Delta g}{g} \right)^2 + [\omega_{gq} \Delta q] \left(\frac{\Delta g}{g} \right) + [\omega_{qq} \left(\frac{\Delta q}{q} \right)^2]$$



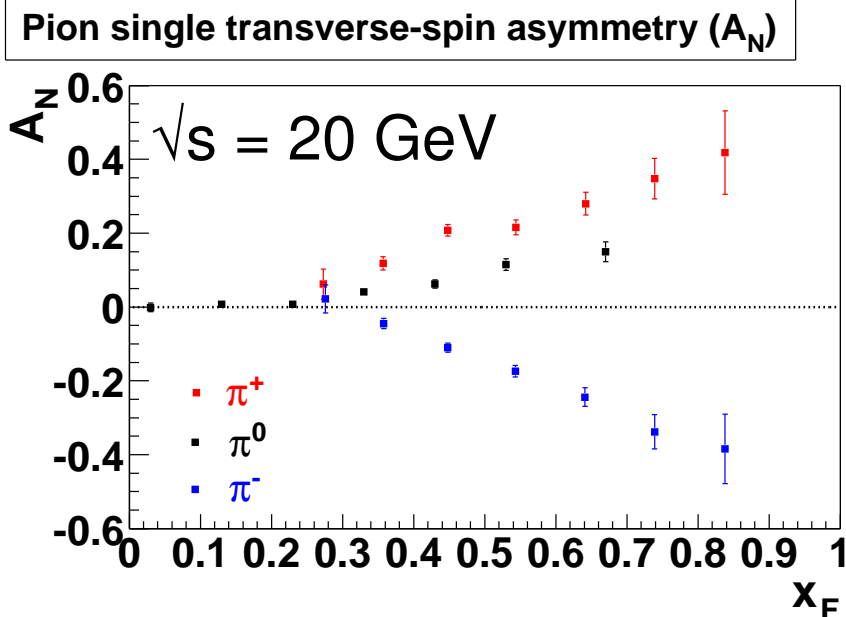
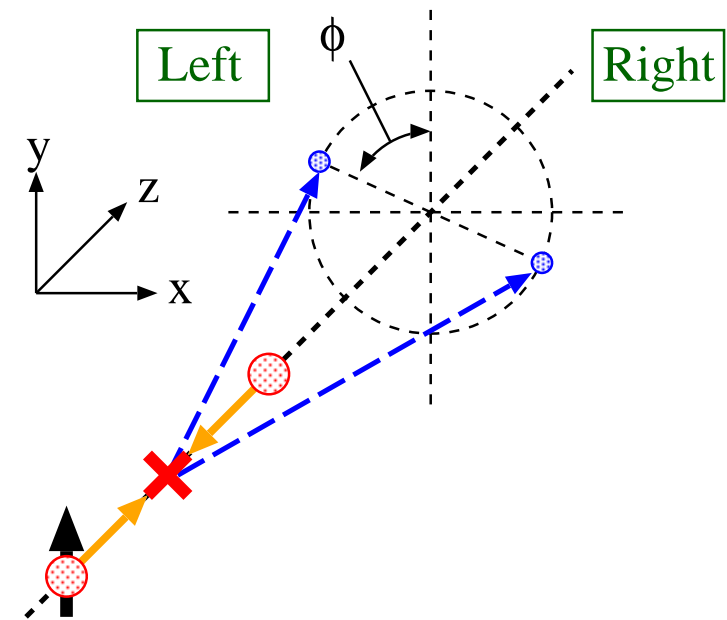
Spin Physics at RHIC-PHENIX

Single Transverse Spin Asymmetry

Left - right asymmetry by transversely polarized beam.

$$A_N = \frac{1}{\sin(\phi)} \frac{\sigma(\phi) - \sigma(\phi - \pi)}{\sigma(\phi) + \sigma(\phi - \pi)}$$

Several approaches are suggested.
(Collins effect, Sivers effect, Twist-3...)



> A_N of pions is measured by many experiment.
(E704, STAR, BRAHMS)

> A_N of pion, neutron is measured by PHENIX

Spin Physics at RHIC-PHENIX

Anti-quark distribution ($\Delta\bar{q}$) with W

W coupling is flavor sensitive.

($u\bar{d} \rightarrow W^+$, $\bar{u}d \rightarrow W^-$)

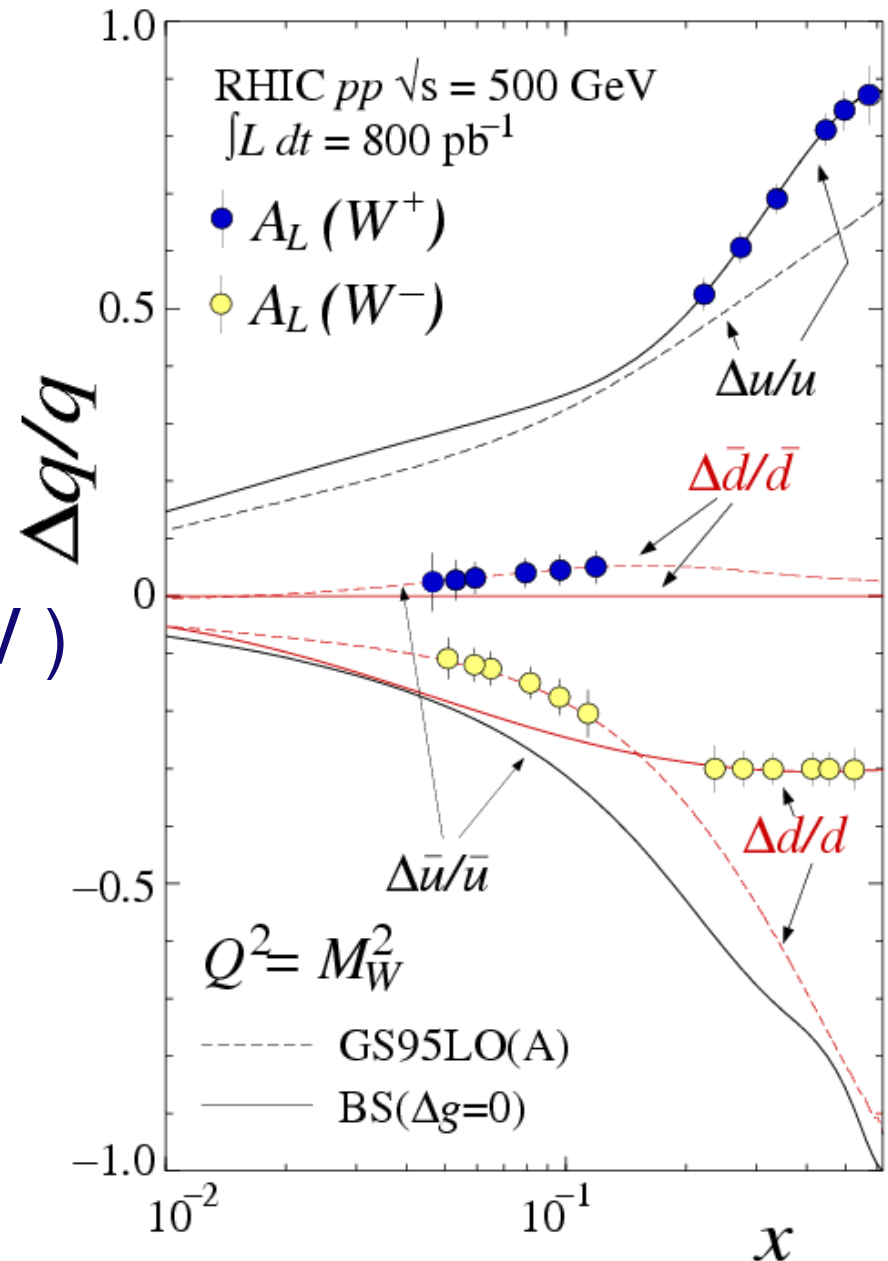
---> Anti-quark distribution can be extracted.

The operation with $\sqrt{s} = 500$ GeV is planned in the future.
(Currently basic setup is 200 GeV)

Measure parity violating A_L .

$$A_L(W^+) = \frac{\Delta u \cdot \bar{d} - \Delta\bar{d} \cdot u}{\Delta u \cdot \bar{d} + \Delta\bar{d} \cdot u}$$

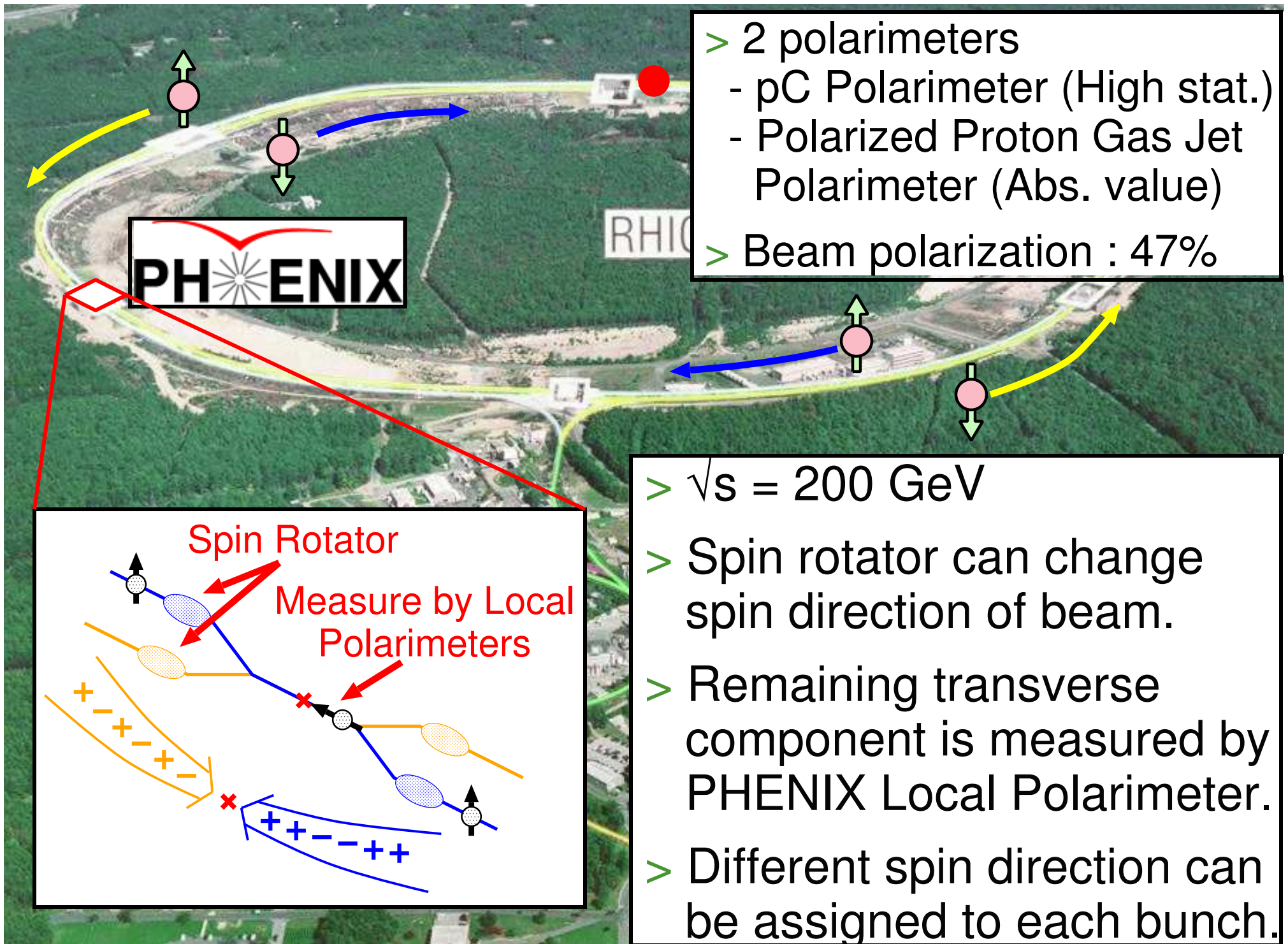
$$A_L(W^-) = \frac{\Delta d \cdot \bar{u} - \Delta\bar{u} \cdot d}{\Delta d \cdot \bar{u} + \Delta\bar{u} \cdot d}$$



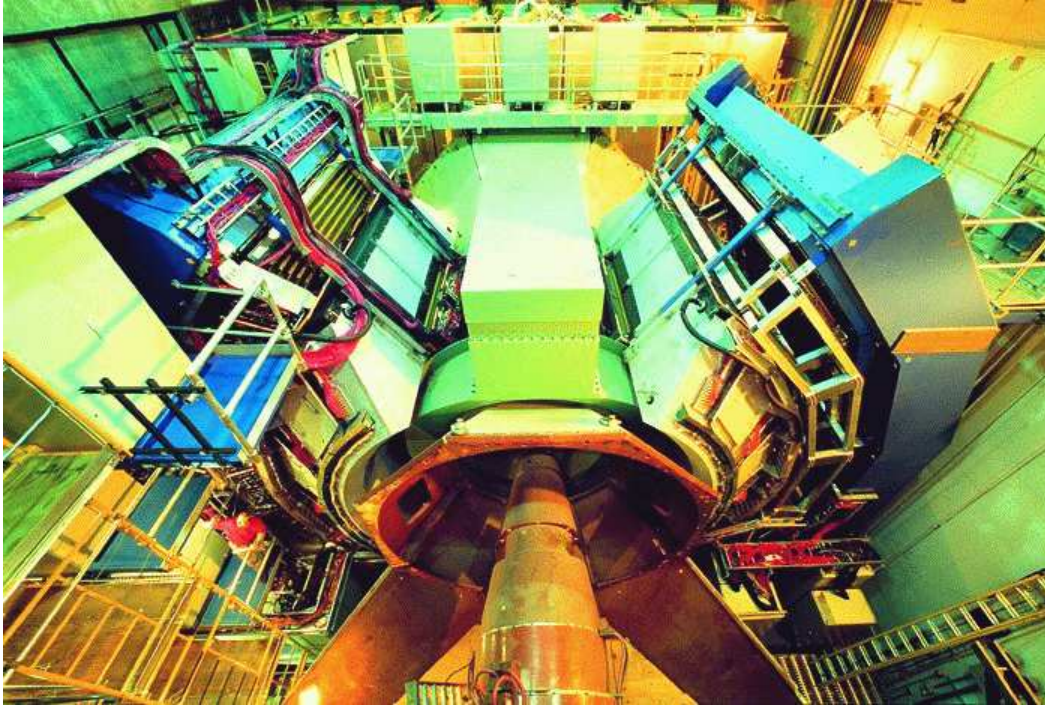
RHIC



RHIC



PHENIX



Beam-Beam-Counter & Zero Degree Counter

- > BBC : $3.0 < |\eta| < 3.9$
- > ZDC : $|\eta| > 6.6$ ($\theta > 2.8\text{mrad}$)
- > Minimum Bias Trigger (BBC)
- > Relative Luminosity (BBC&ZDC)
- > Local Polarimeter (ZDC)
- > Physics : Neutron (ZDC)

Central Arm

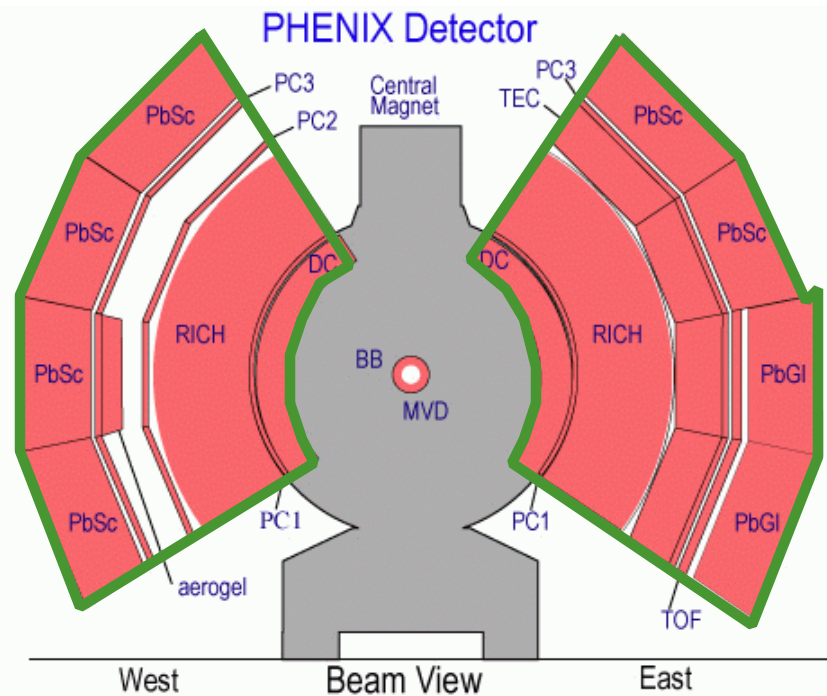
- > $|\eta| < 0.35$, $\Delta\phi = \pi$
- > EMCal, RICH, Tracker
- > Physics : π^0 , photon, charged hadrons, electron.



Muon Arm

- > $1.2 < |\eta| < 2.4$
- > Muon Identifier, Muon Tracker.
- > Physics : muon, J/ψ , W

PHENIX



Beam-Beam-Counter & Zero Degree Counter

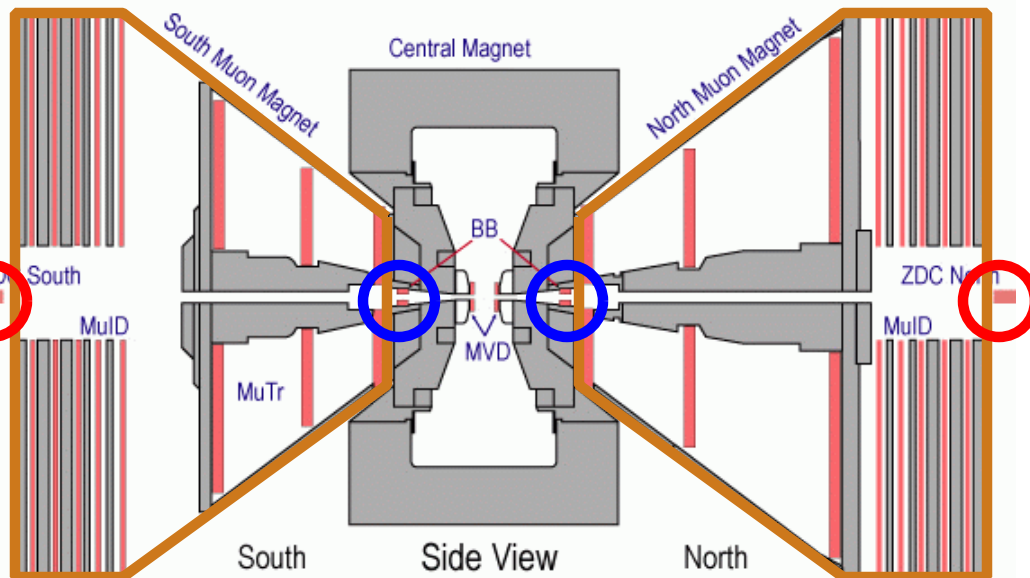
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Central Arm

- > $|\eta| < 0.35$, $\Delta\phi = \pi$
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Muon Arm

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- > Physics : muon, J/ψ , W



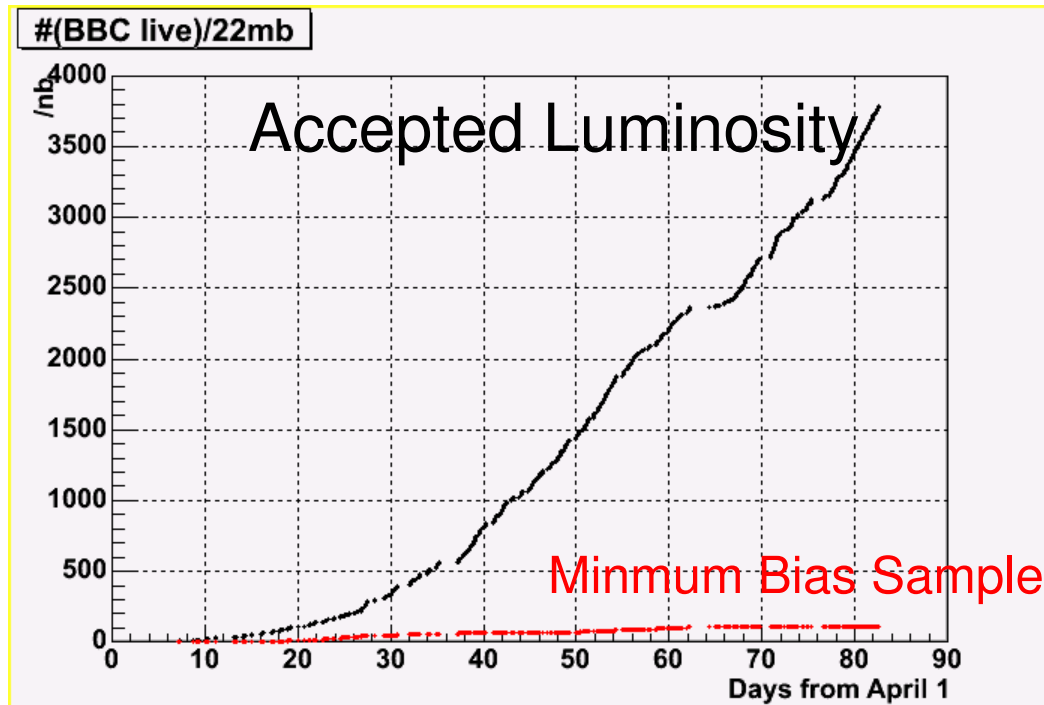
Luminosity & History

2001-2002 transverse spin run (First polarized proton run)
 $P=15\%$ $L=0.15 \text{ pb}^{-1}$

2003 longitudinal spin run
 $P=27\%$ $L=0.35 \text{ pb}^{-1}$ $\text{FOM}=1.86 \text{ nb}^{-1}$

2004 commissioning run (longitudinal spin)
 $P=40\%$ $L=0.12 \text{ pb}^{-1}$ $\text{FOM}=3.1 \text{ nb}^{-1}$

2005 longitudinal spin run (w/ short transverse spin run)
 $P=47\%$ $L=3.8 \text{ pb}^{-1}$ $\text{FOM}=185 \text{ nb}^{-1}$



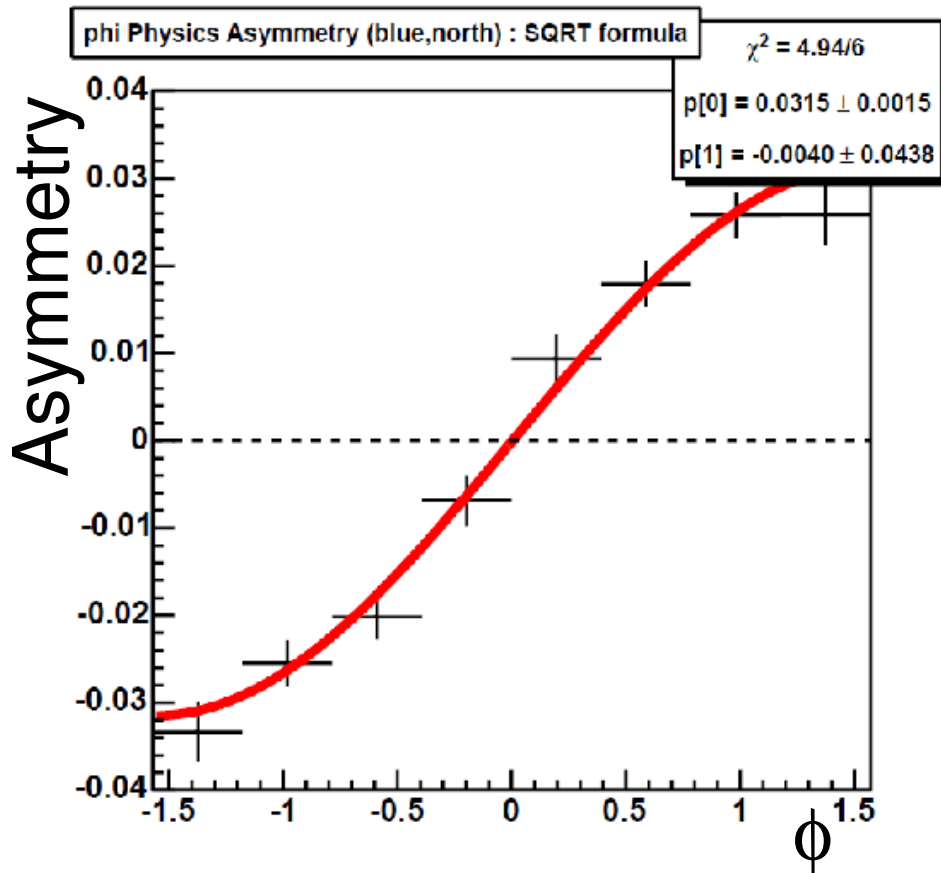
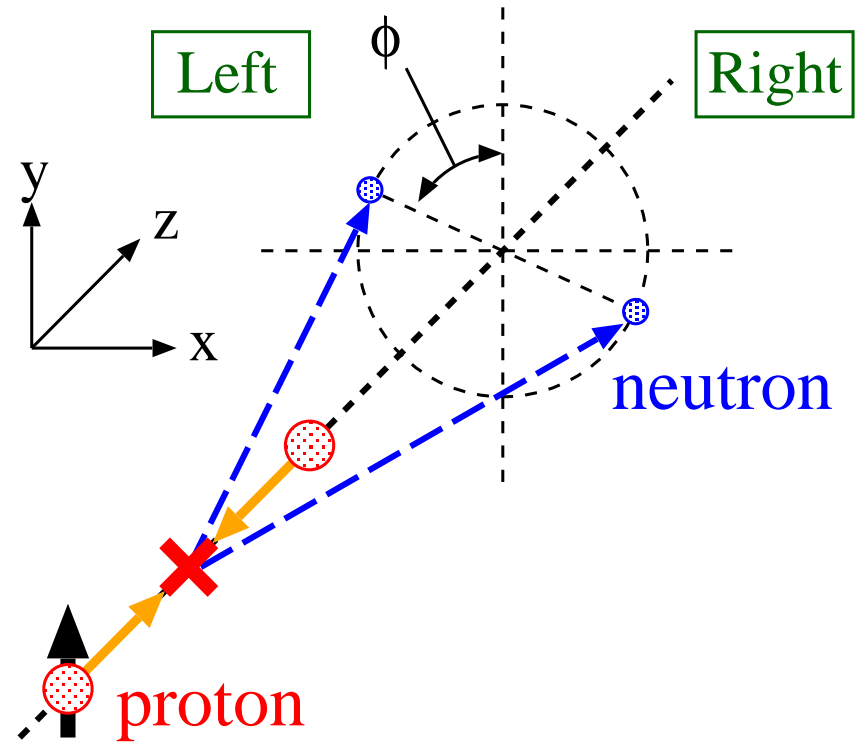
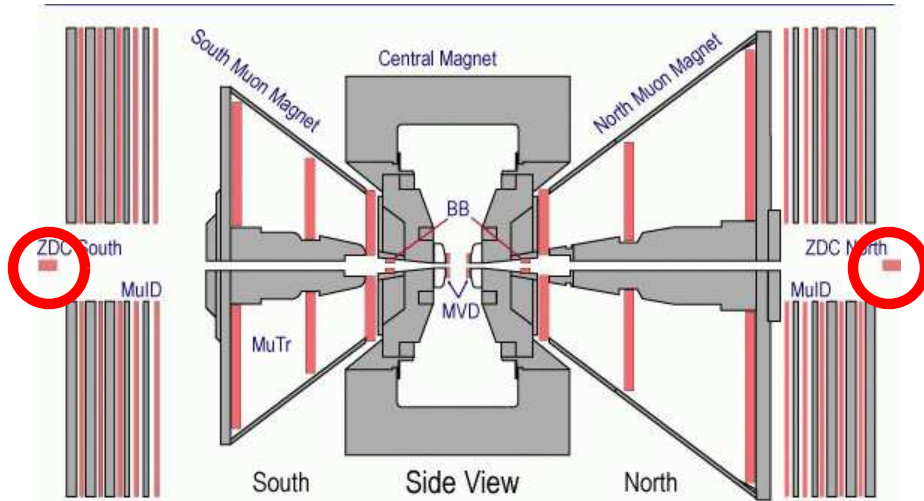
$\text{FOM} : \text{Figure of merit} = P^4 L$

We had first long longitudinal spin run in 2005.

Figure of merit is 40 times larger than past years.

Local Polarimeter

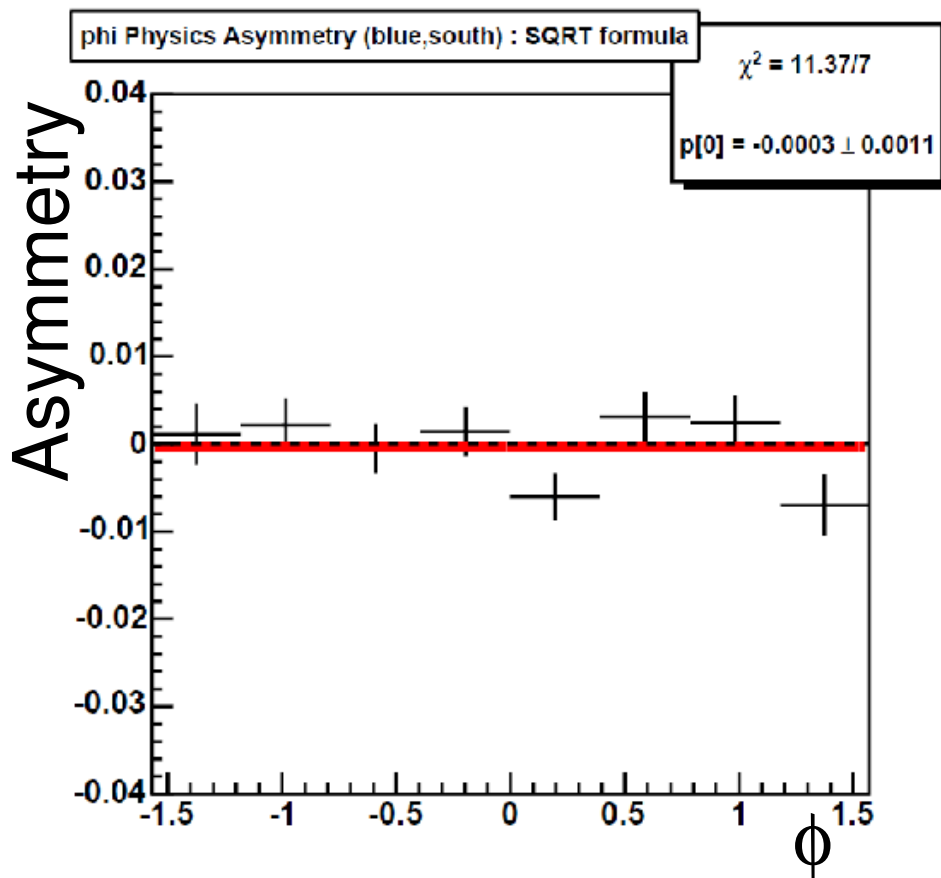
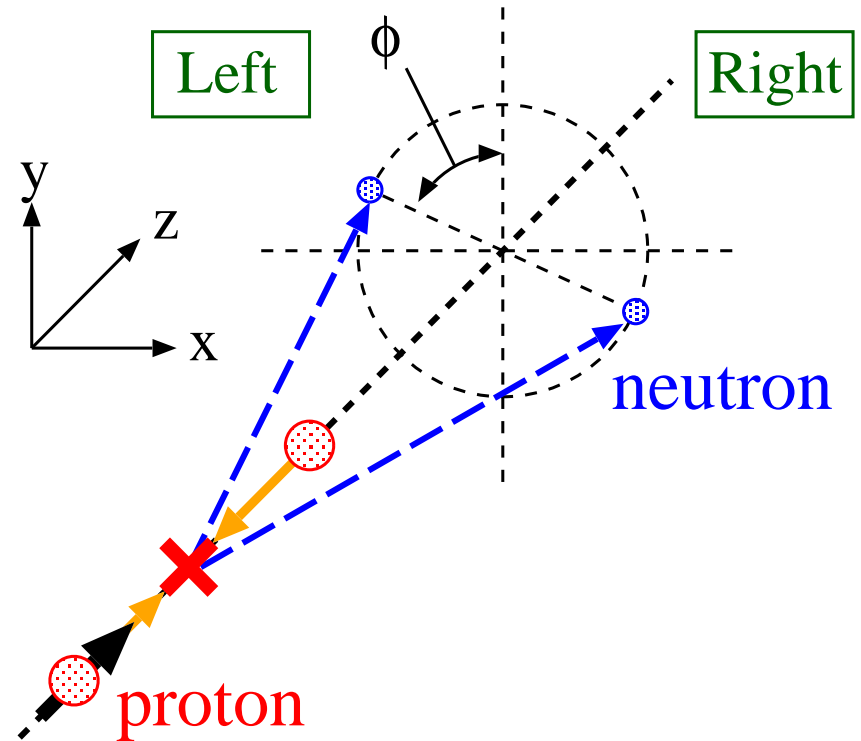
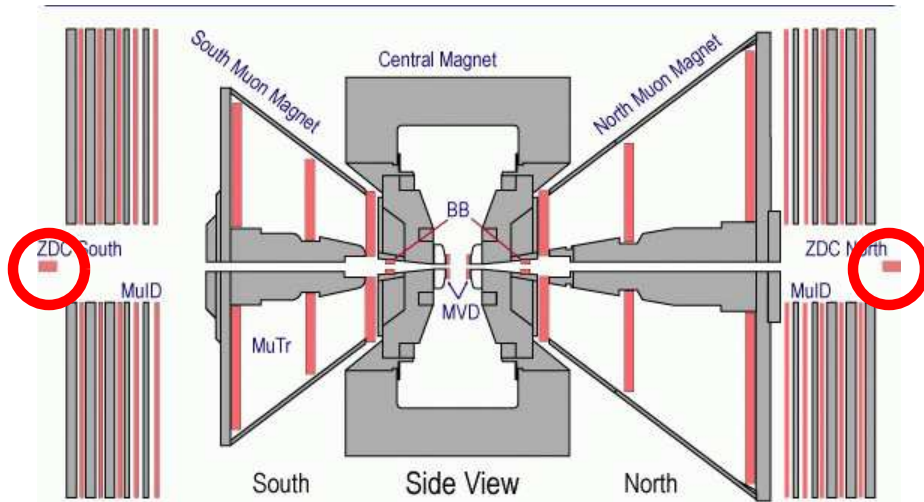
Measure A_N of neutron in very forward region.



Rotator **OFF**
Clear asymmetry is measured.

Local Polarimeter

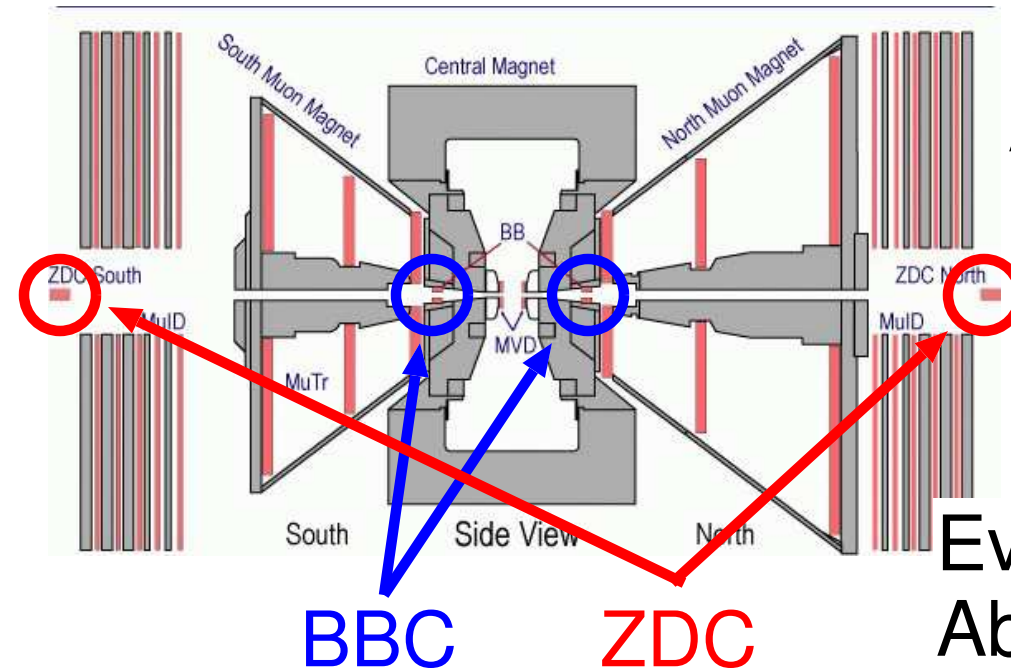
Measure A_N of neutron in very forward region.



Rotator **ON**
Asymmetry disappears.

Longitudinal component $> 98\%$

Relative Luminosity



$$A_{LL} = \frac{1}{P \cdot P} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \quad R = \frac{L_{++}}{L_{+-}}$$

P : Beam polarization

N : Number of measured particles

R : Relative Luminosity

Events detected by BBC are used.
Absolute scale is not necessary.

Systematic uncertainty evaluation

> Compare two detector with different acceptance.

- BBC : $3.0 < |\eta| < 3.9$
- ZDC : $|\eta| > 6.6$ ($\theta < 2.8$ mrad)

$$r(i) = \frac{N_{ZDC}(i)}{N_{BBC}(i)} \text{ should be constant.}$$

(i : crossing number)

Relative Luminosity

Compare two rel. lum. detectors : BBC vs. ZDC

$$r(i) = \frac{N_{\text{ZDC}}(i)}{N_{\text{BBC}}(i)} \text{ should be constant. (} i : \text{ crossing number)}$$

Fit $r(i)$ to $C[1 + \alpha P_B(i)P_Y(i)]$: α is possible asymmetry.

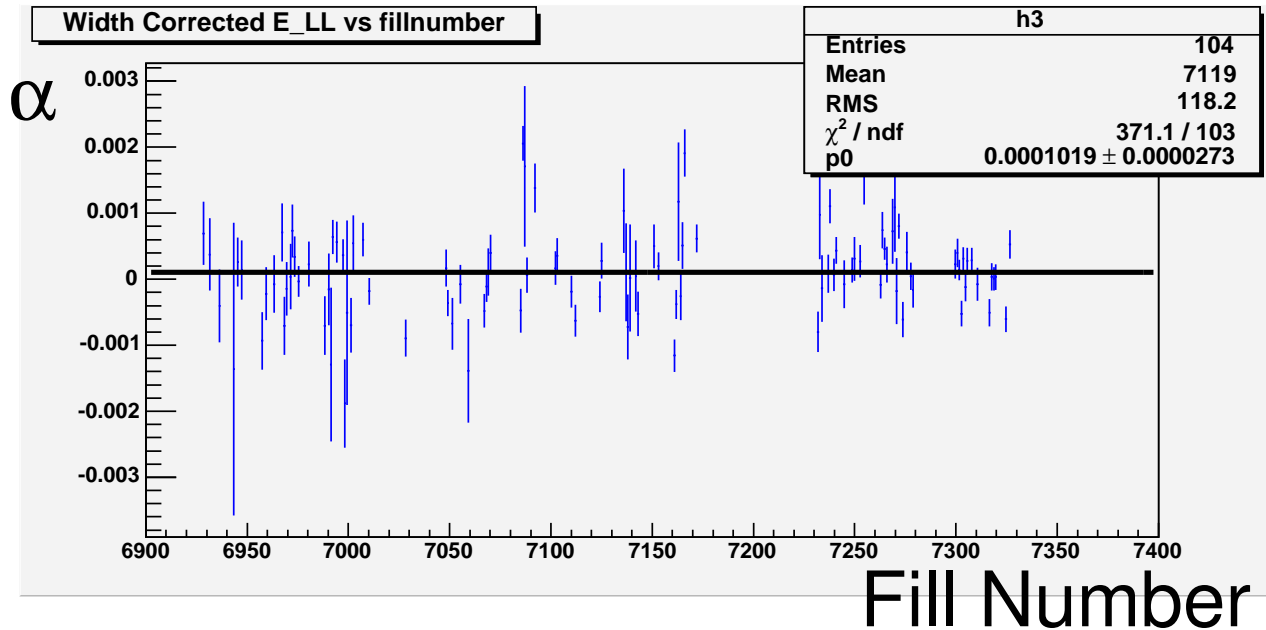
$$\delta A_{\text{LL}} \text{ from rel. lum. is } \frac{\delta R}{2 P_B P_Y} = \frac{\delta \alpha}{P_B P_Y}$$

After renormalization
by chisquare,

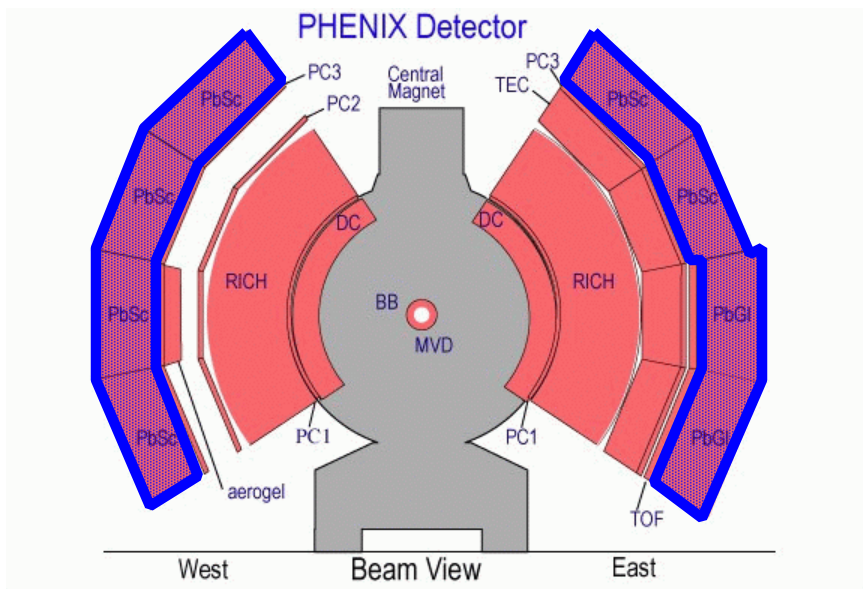
a) $\delta R = 1.0 \times 10^{-4}$

b) $\delta A_{\text{LL}} = 2.3 \times 10^{-4}$
for 47% beam
polarization

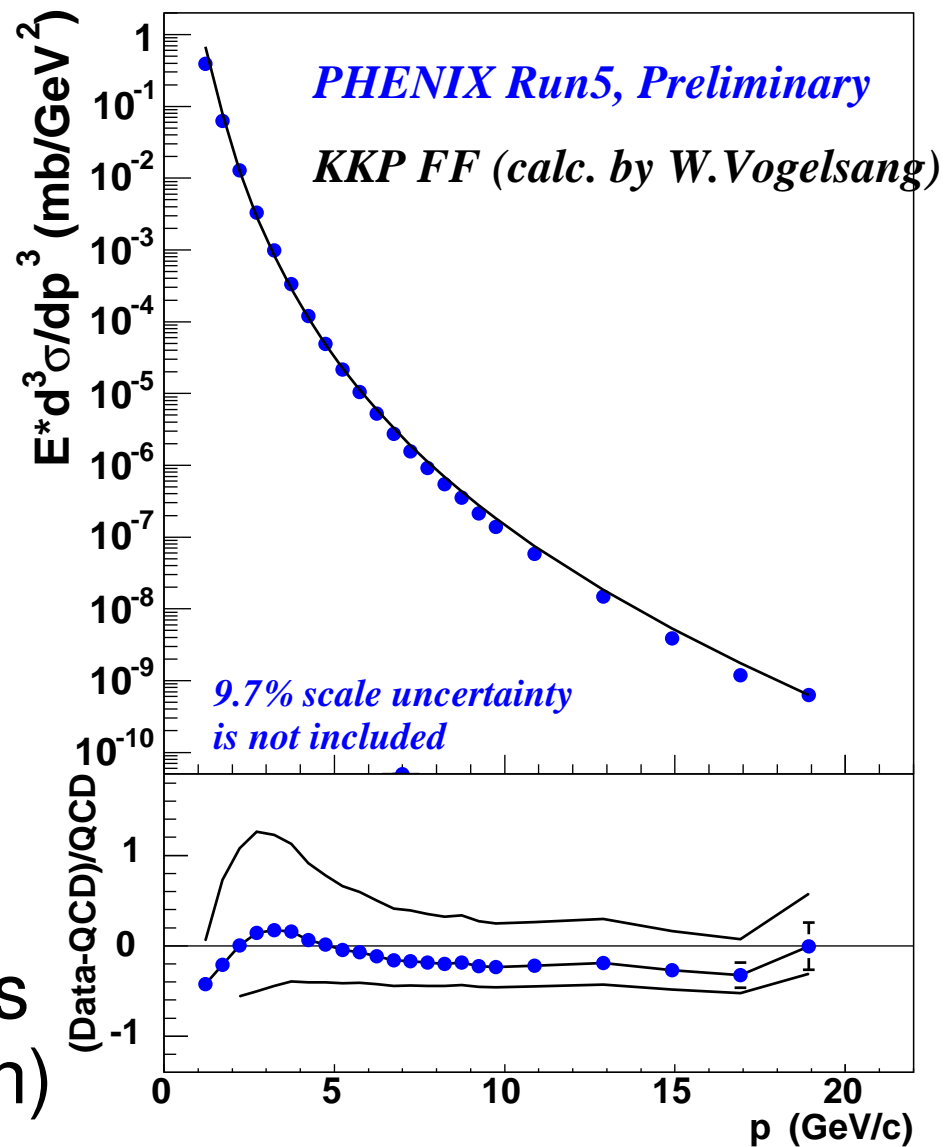
c) A_{LL} of BBC relative
to ZDC is
consistent with 0



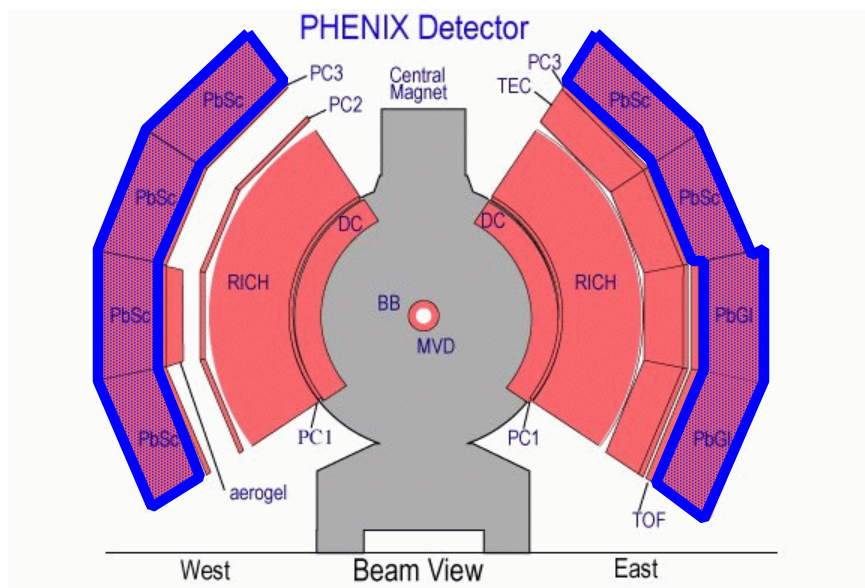
PHENIX results - neutral pion



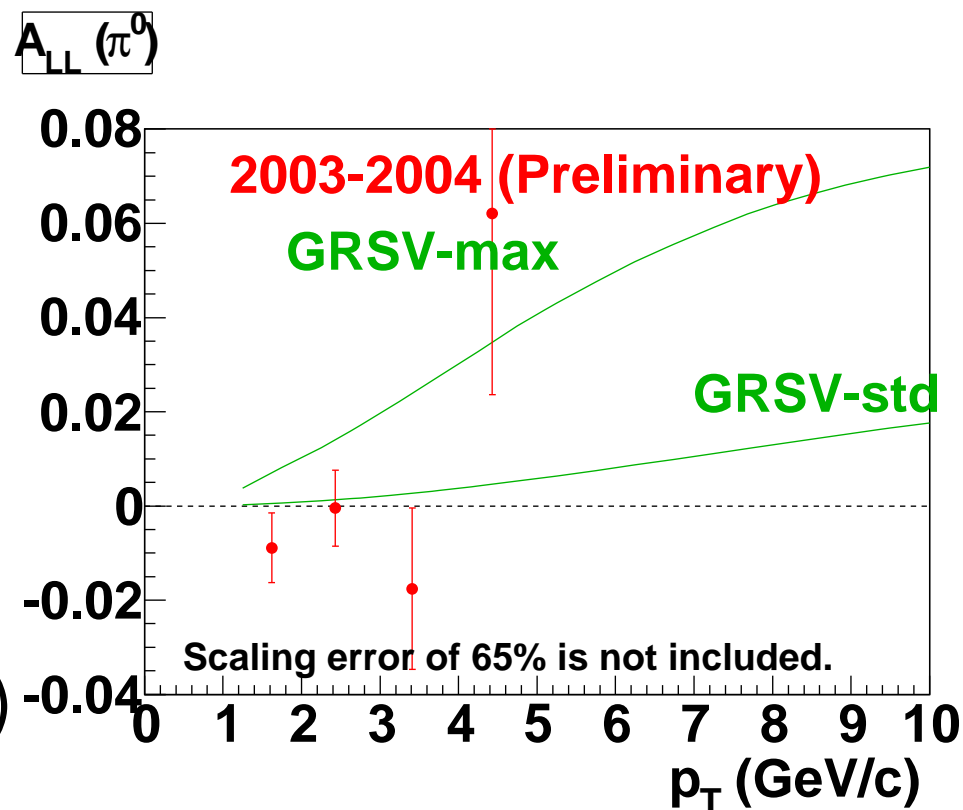
- > Clean measurement by fine segmented EMCal.
($\Delta\eta \cong \Delta\phi \cong 0.01$)
- > High statistics
- > pQCD calculation describes the data well. (cross section)



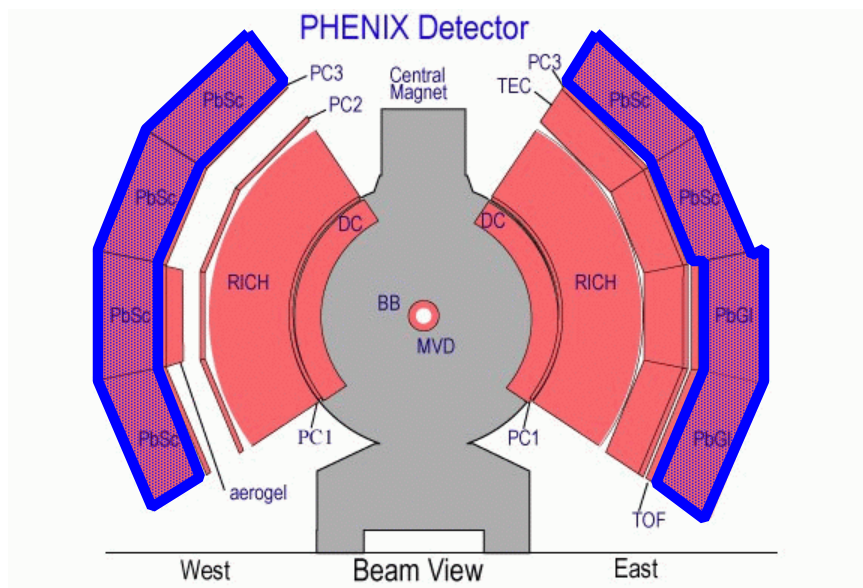
PHENIX results - neutral pion



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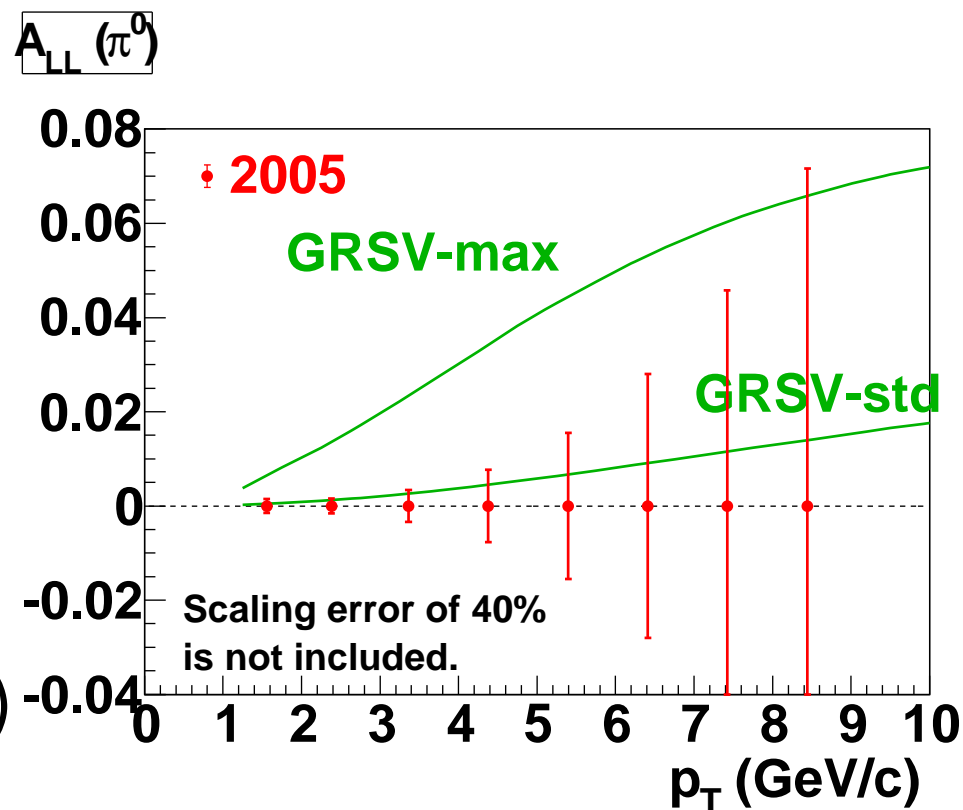
PHENIX results - neutral pion



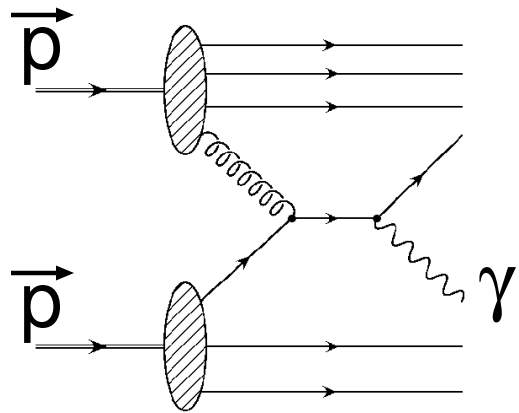
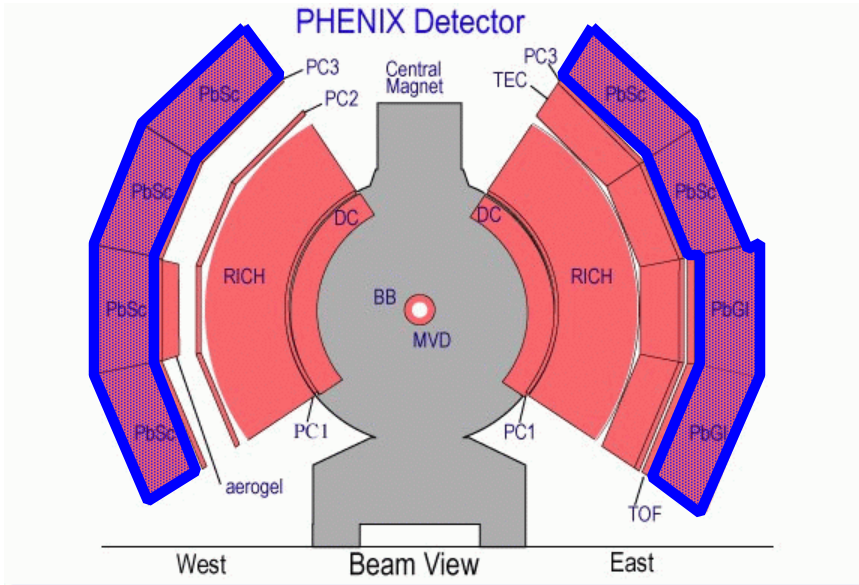
Statistical error becomes much smaller.
GRSV-std and GRSV-max can be distinguished.

---> K. Boyle's talk in section III.4

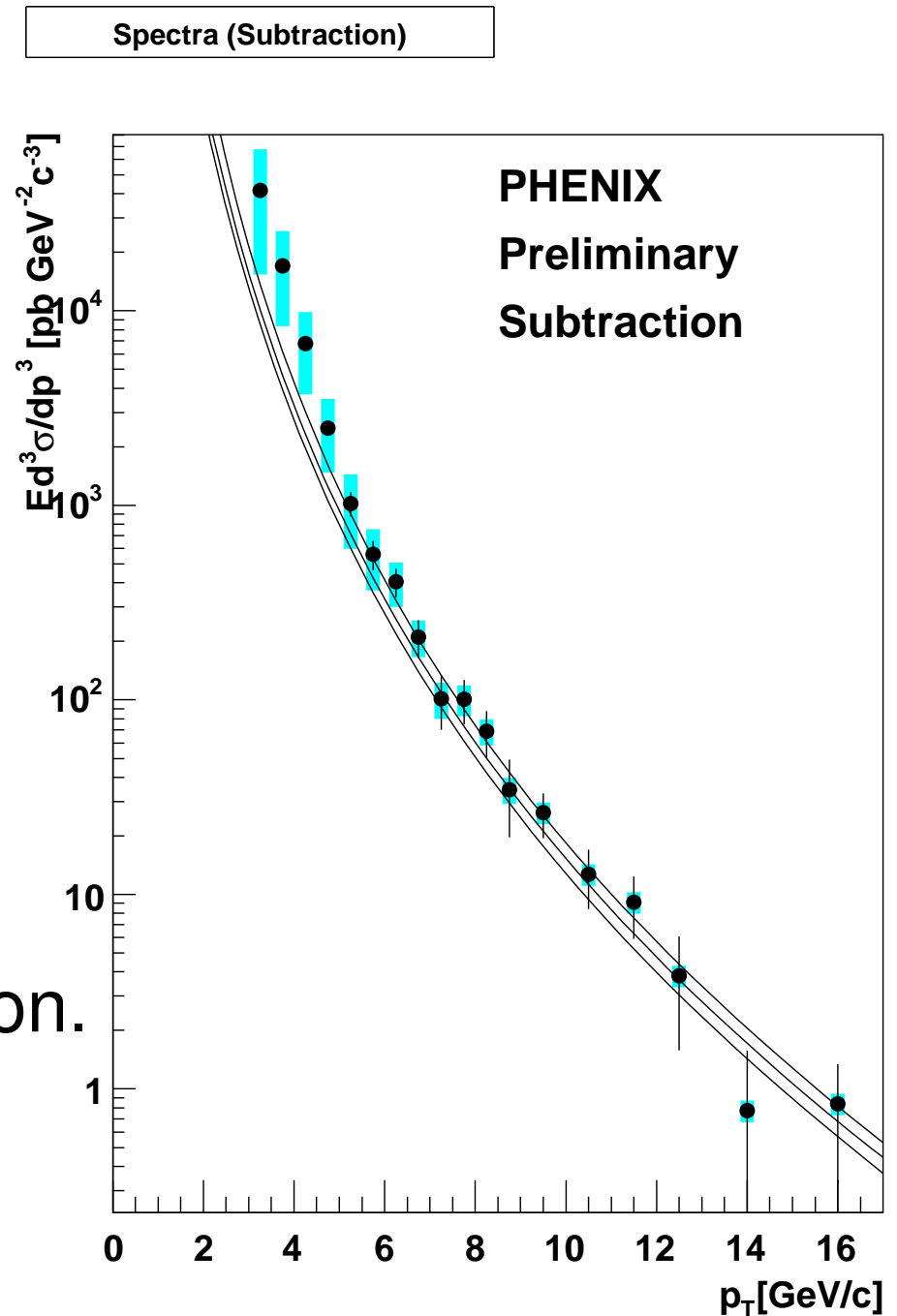
- > Clean measurement by fine segmented EMCal. ($\Delta\eta \cong \Delta\phi \cong 0.01$)
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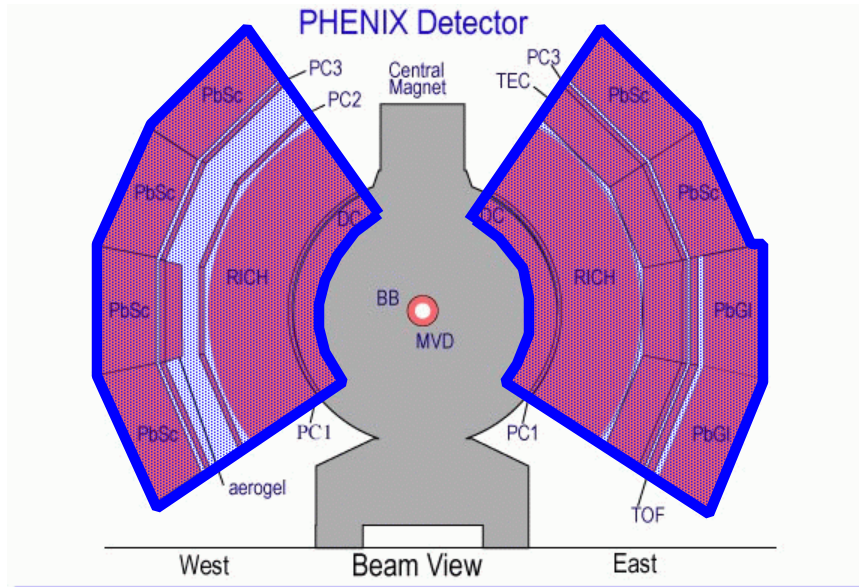
PHENX results - Direct photon



- > Independent from fragmentation.
- > Sensitive to sign of Δg
- > Low statistics
- > Theory describes data well at $p_T > 5 \text{ GeV}/c$

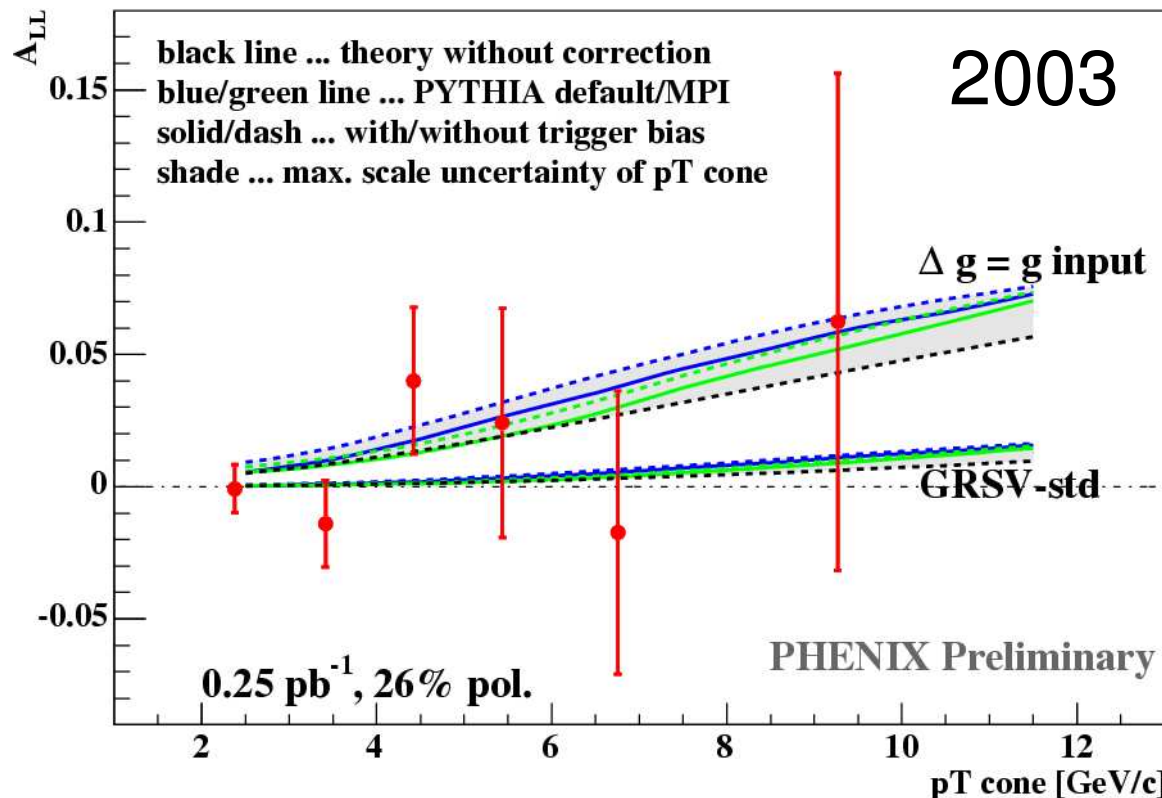


PHENIX results - "Jet"



"Jet" detection

Tag one high energy photon and sum energy of nearby photons/charged particles.



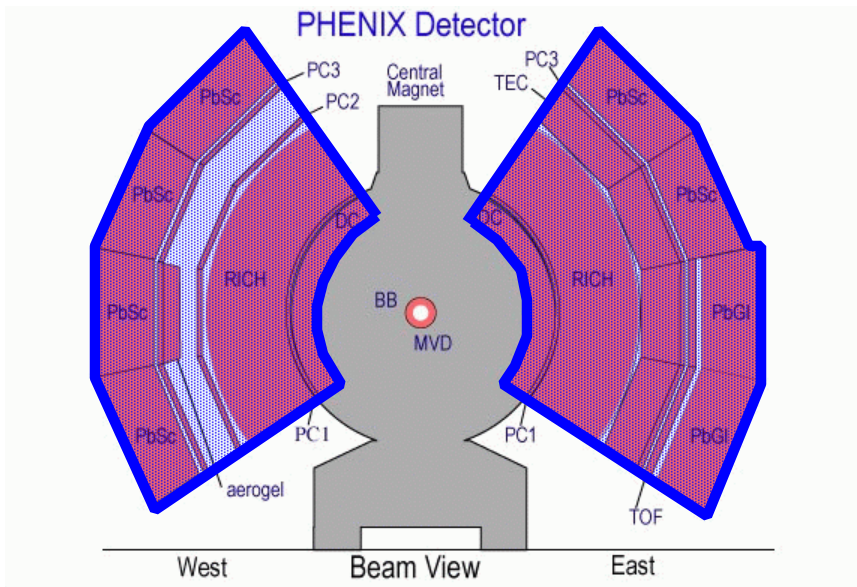
Definition of "pT cone"

Sum of pT measured by EMCal & Tracker with

$$R = \sqrt{|\phi|^2 + |\eta|^2} < 0.3$$

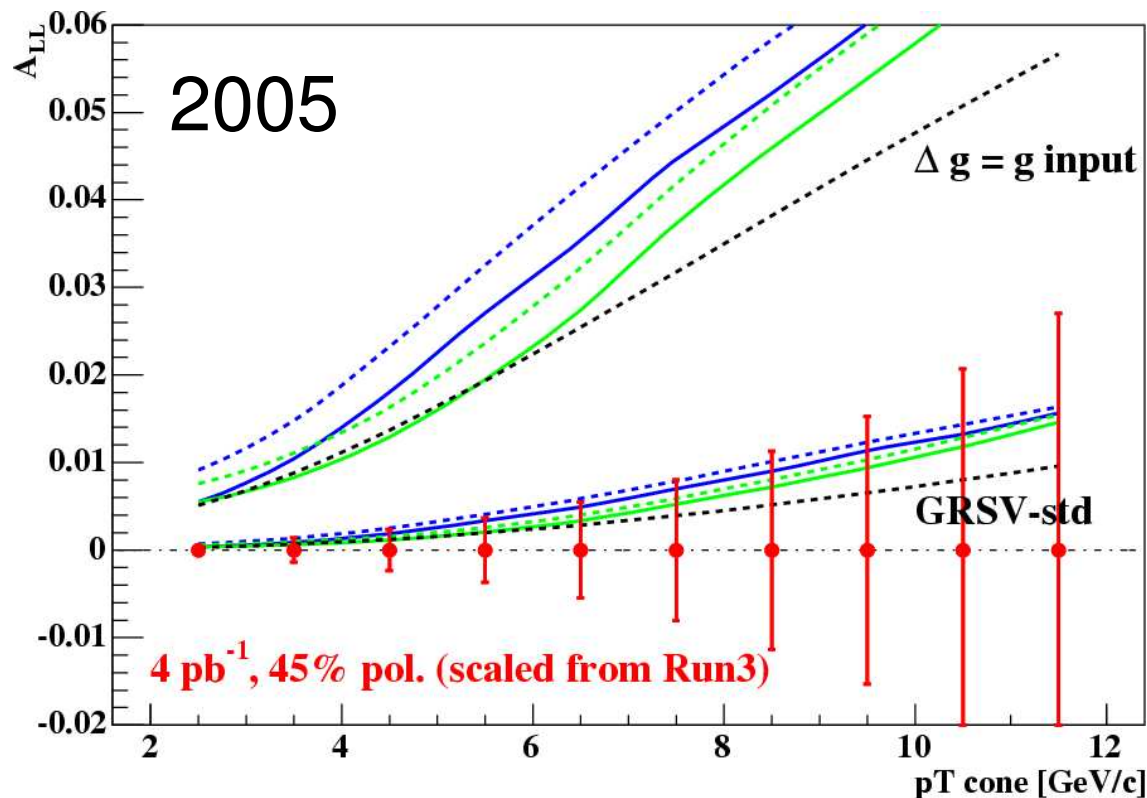
Real pT of jet is evaluated by modified PYTHIA.

PHENIX results - "Jet"



"Jet" detection

Tag one high energy photon and sum energy of nearby photons/charged particles.



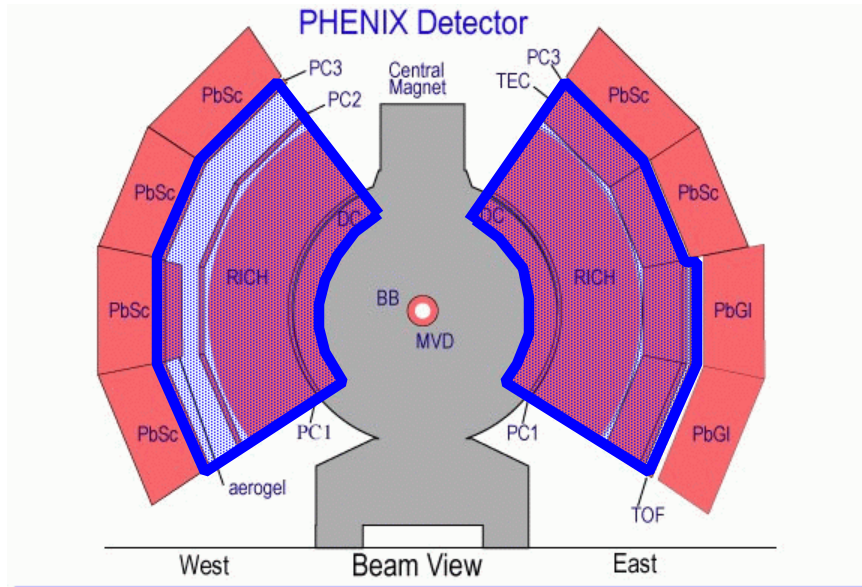
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Sum of pT measured by EMCal & Tracker with

$$R = \sqrt{|\phi|^2 + |\eta|^2} < 0.3$$

Real pT of jet is evaluated by modified PYTHIA.

PHENIX results - A_N of pions

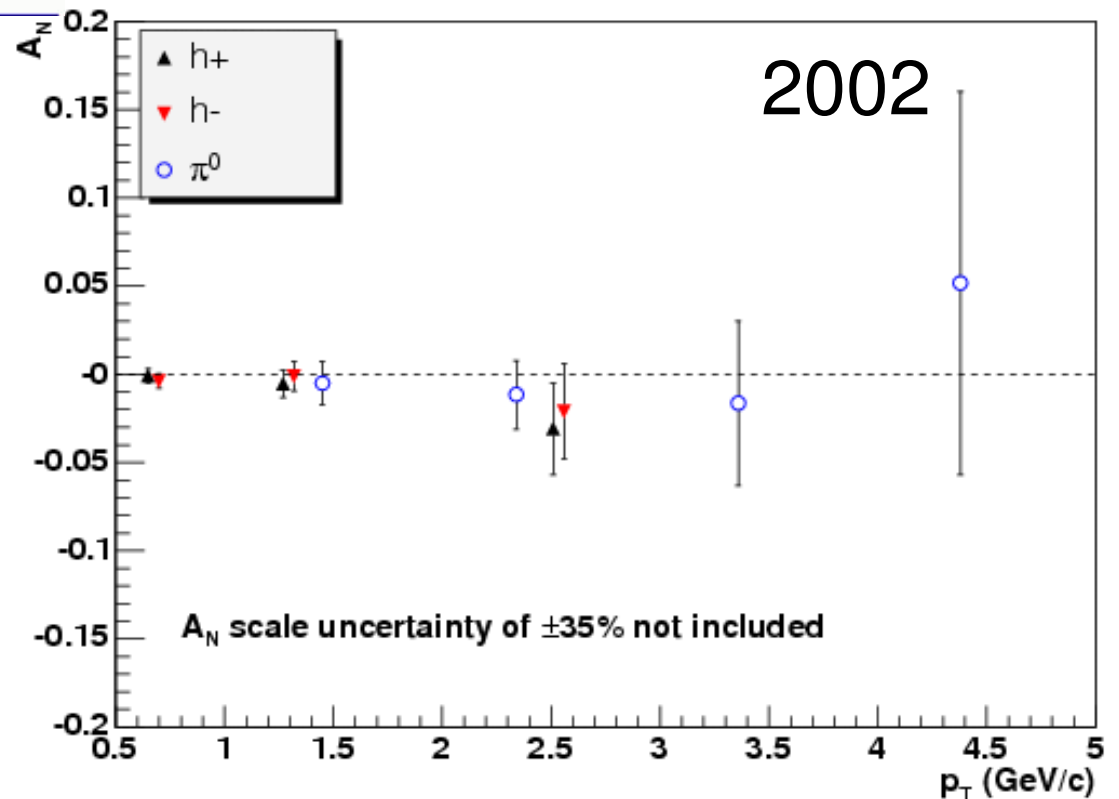


Large asymmetry is observed in forward region. (E704, STAR...)

PHENIX measured A_N of charged hadrons and pions in central region.

Results of charged pion from 2005 run.

---> K. Eyser's talk in section III.7



Other topics

- > **Single electron, D**
 - Tagging charm quark for Δg
- > **J/ ψ**
 - Production mechanism
 - ALL for Δg
 - > M. Liu's talk in section III.4
- > **μ**
 - A_N
 - > H. Bataineh in poster session
 - > A. Purwar in poster session
- > **Helicity correlated differences in Jet k_T**
 - This may suggest evidence of orbital angular momentum.
 - > R. Hobbs's talk in section III.6
- > **A_N of Jet k_T**
 - Access to Sivers function
- > **η**
 - ALL for polarized PDFs
 - > J. Seele in poster session
- > **Λ**
 - Spin transfer
 - ALL for polarized PDFs

RHIC-PHENIX in the future

> Silicon Vertex Tracker

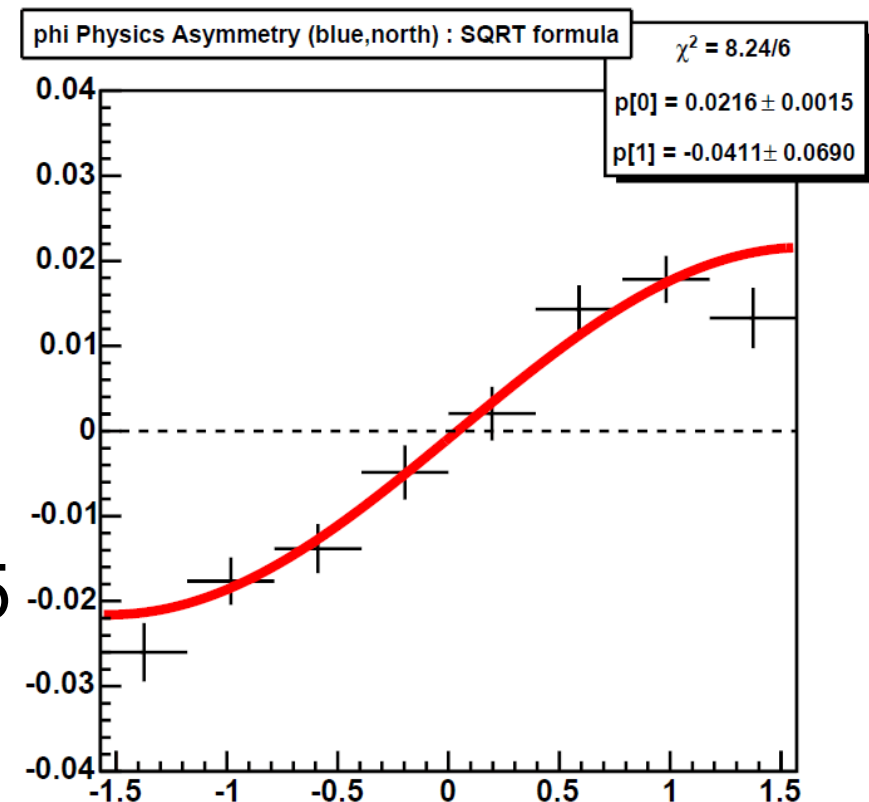
- 2 pixel layer + 2 strip layer
- Wider acceptance for Jet
- Displaced vertex measurement for heavy flavor tagging.

> Muon Trigger Upgrade

- For $W \rightarrow \mu$ measurement at $\sqrt{s} = 500$ GeV
- Resistive Plate Chamber (Timing, Momentum)

> Toward $\sqrt{s} = 500$ GeV

- 410 GeV commissioning in 2005
- We observed neutron asymmetry at $\sqrt{s} = 410$ GeV.

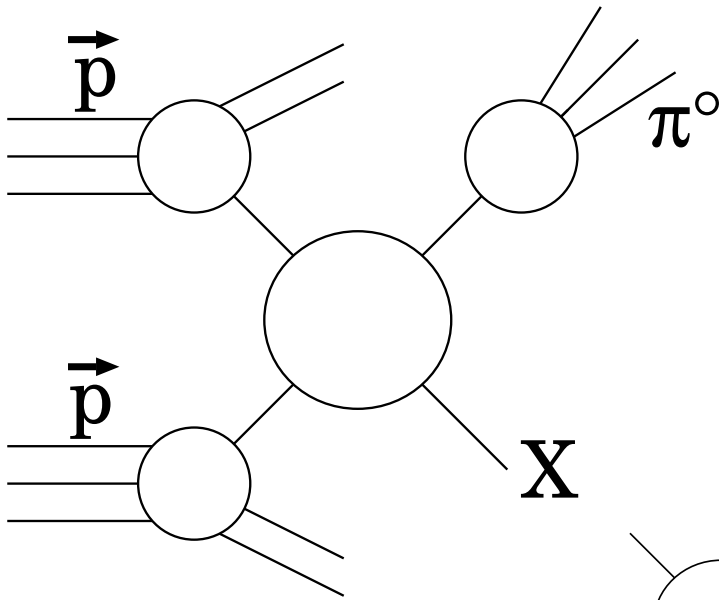


Summary

- > PHENIX just has taken first long longitudinal-spin polarized-proton collision data in Run-5 (2005).
 - > 40 times more statistics in figure of merit for ALL.
- > Δg measurement
 - GRSV-std and GRSV-max can be distinguished by ALL in π^0 production.
 - The study of other channel is on going.
- > Many other works in hard effort
 - Single transverse-spin asymmetry
 - Spin correlation in Jet k_T
 - Production mechanism
- > Toward $\sqrt{s} = 500$ GeV run
 - RHIC successfully operated polarized proton run at $\sqrt{s} = 410$ GeV.
 - PHENIX Local Polarimeter measured A_N of neutron at $\sqrt{s} = 410$ GeV.

Spin Physics at RHIC-PHENIX

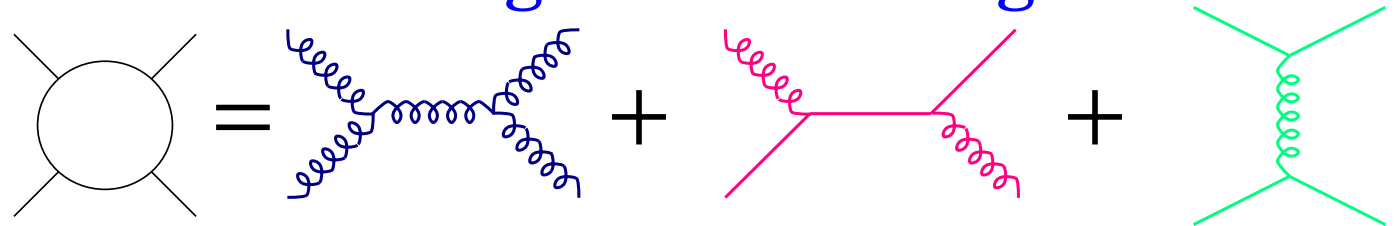
How to measure Δg



Measure A_{LL} in $\vec{p} \vec{p} \rightarrow X$ production.

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$

$$\sim [\omega_{gg}] \left(\frac{\Delta g}{g} \right)^2 + [\omega_{gq} \Delta q] \left(\frac{\Delta g}{g} \right) + [\omega_{qq} (\Delta q)^2]$$



In the experiment, we calculate

$$A_{LL} = \frac{1}{P \cdot P} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \quad R = \frac{L_{++}}{L_{+-}}$$

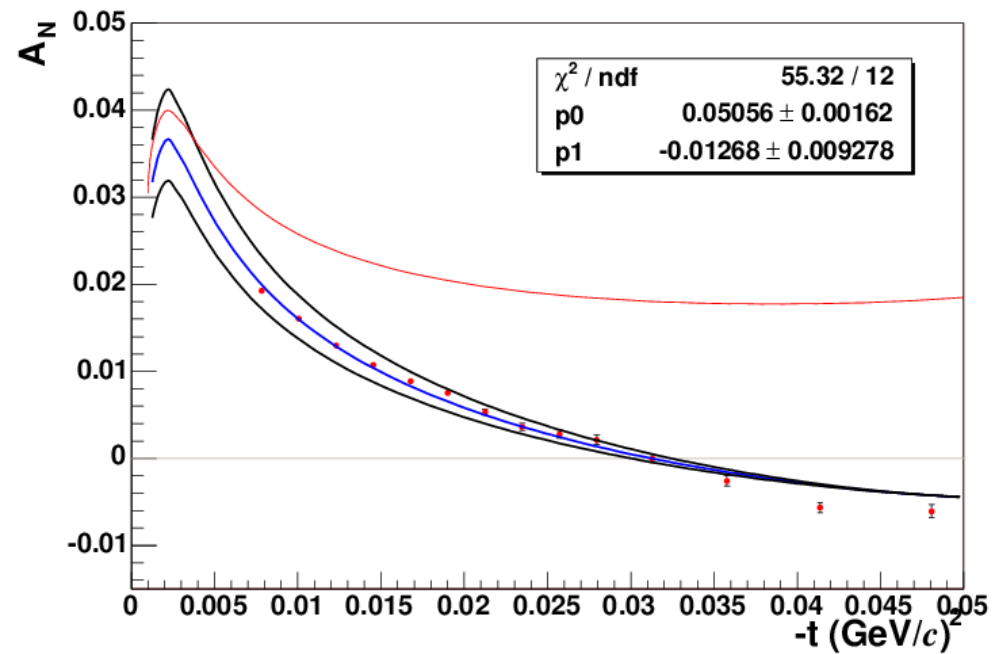
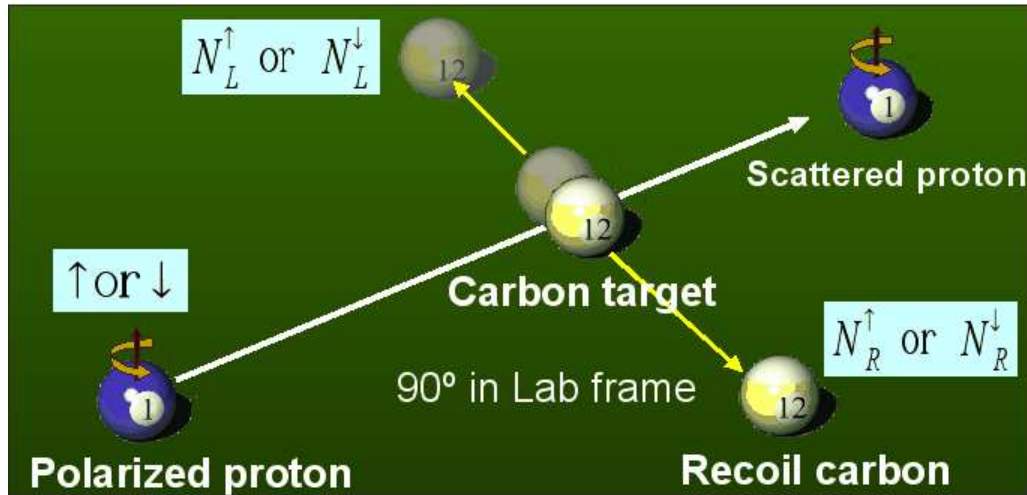
N : Number of particle measured in each helicity state.

P : Beam polarization.

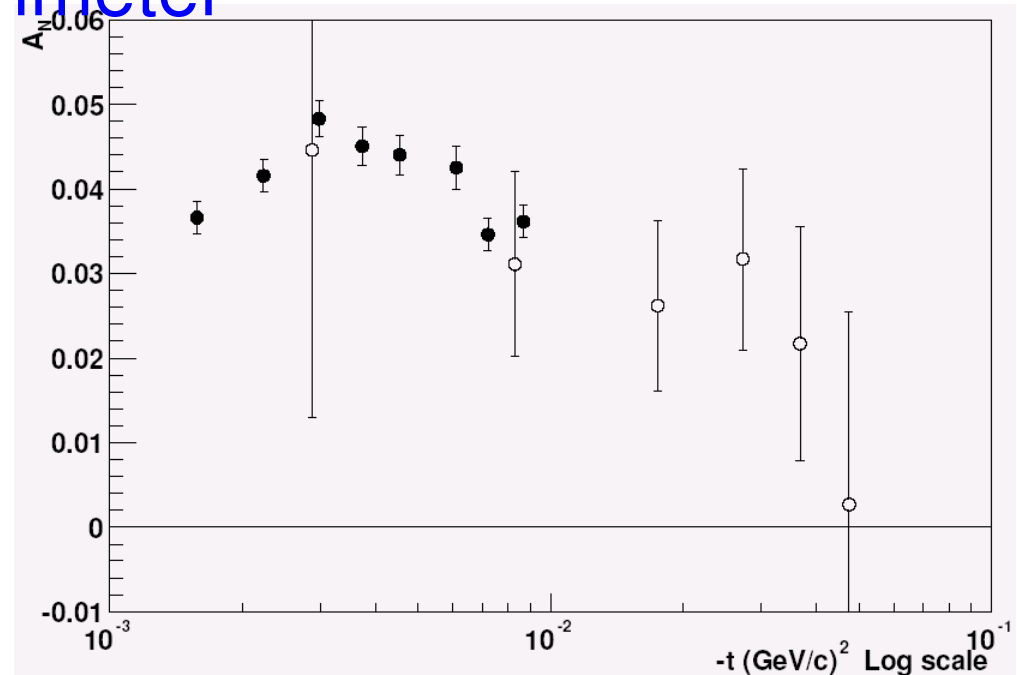
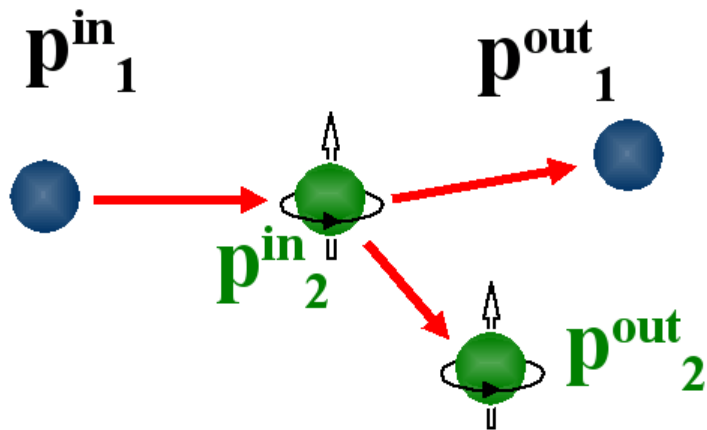
R : Relative Luminosity

Polarimeter

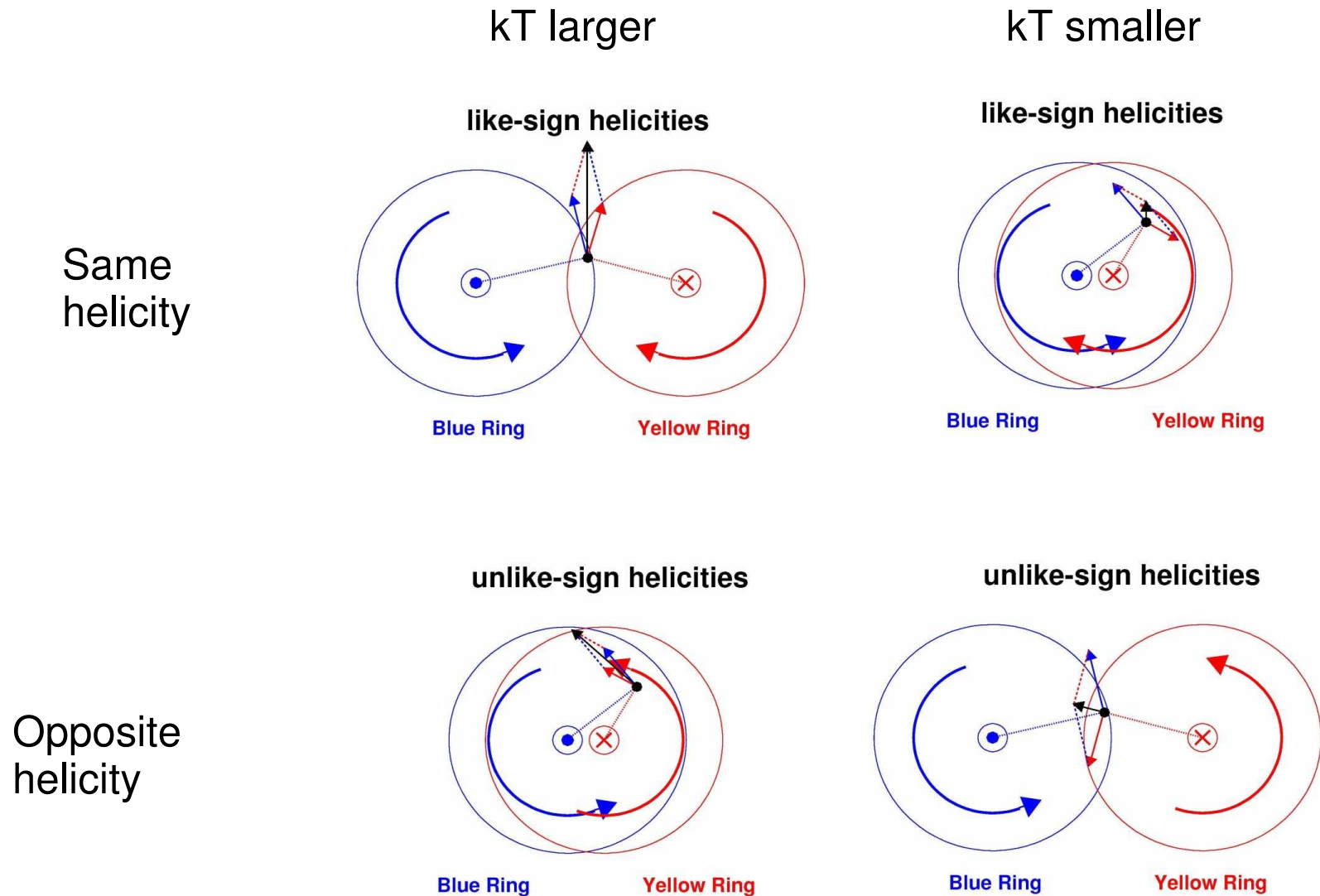
proton-Carbon polarimeter



Polarized proton gas jet polarimeter

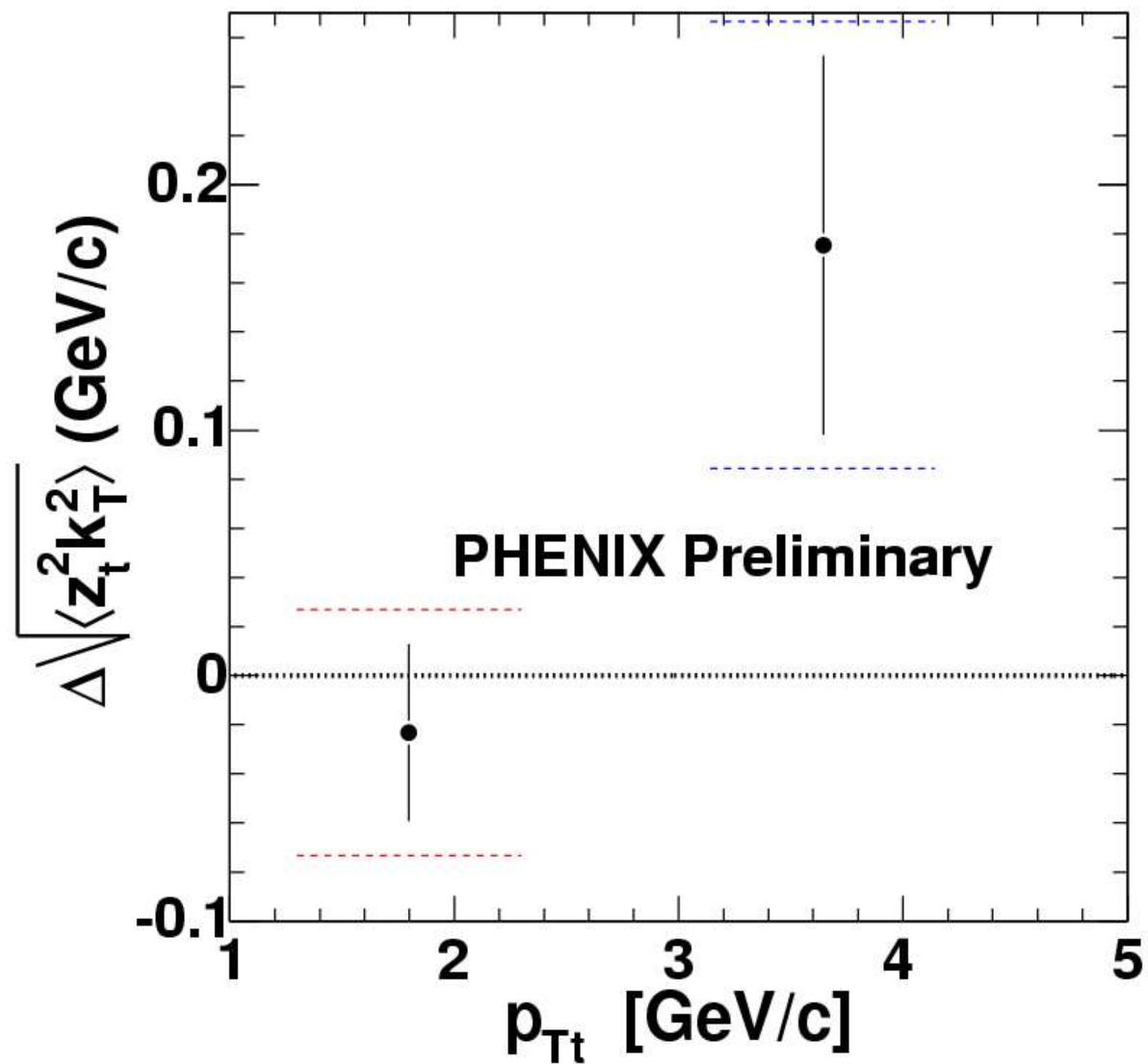


PHENIX results - Jet correlation

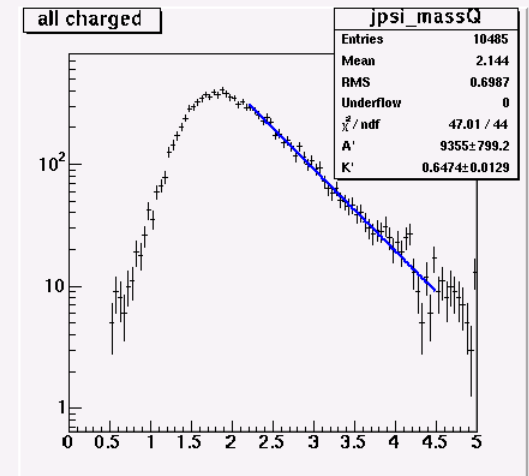
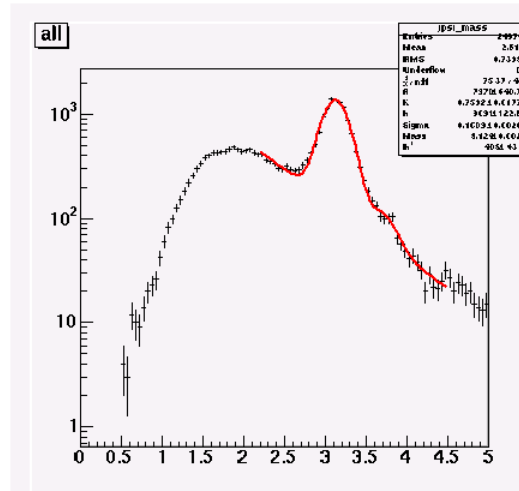
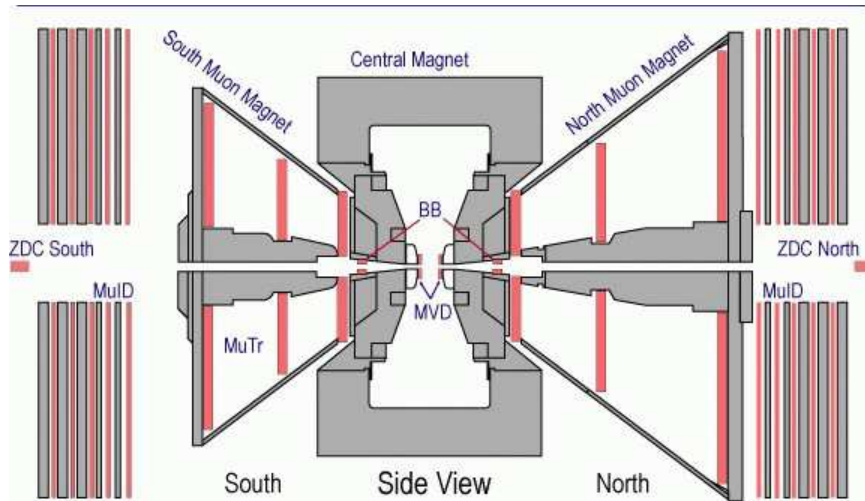


We may observe net effect
after averaging over impact factor.

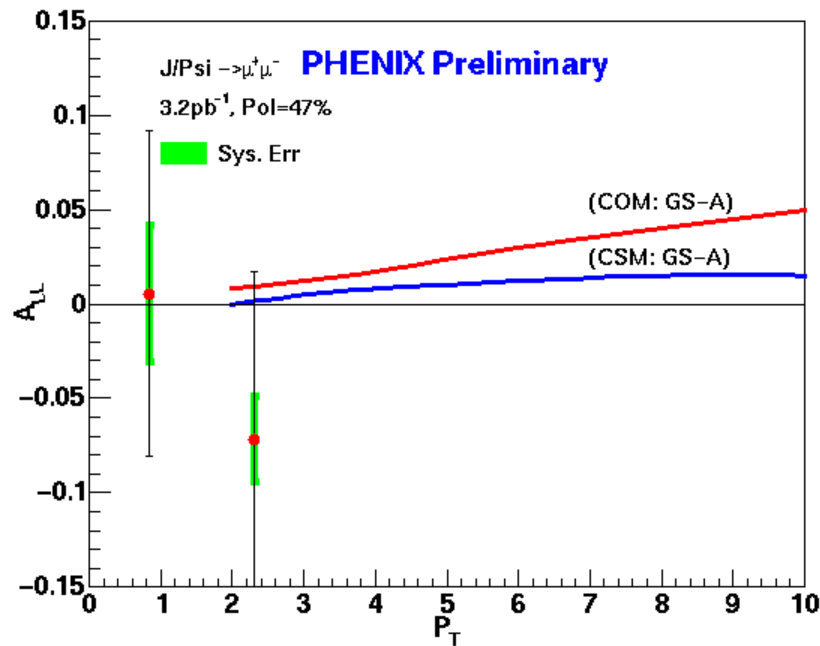
PHENIX results - Jet correlation



PHENIX result - J/psi



J/Psi: $|y| = 1.2-2.4$



(charge +-)-(++, -)

